Volume Four Number Four

SCHOOL OF MINES AND METALLURGY

UNIVERSITY OF MISSOURI

BULLETIN

MAY, 1918

TECHNICAL SERIES

AN INVESTIGATION OF BLENDED PORTLAND CEMENT

ROLLA, MISSOURI
1918

Entered as Second-Class Matter November 29, 1911, at the Post-Office at Rolla, Missouri, under the Act of July 18, 1894. Issued Quarterly.

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SCHOOL OF MINES AND METALLURGY

UNIVERSITY OF MISSOURI

AN INVESTIGATION OF BLENDED PORTLAND CEMENT

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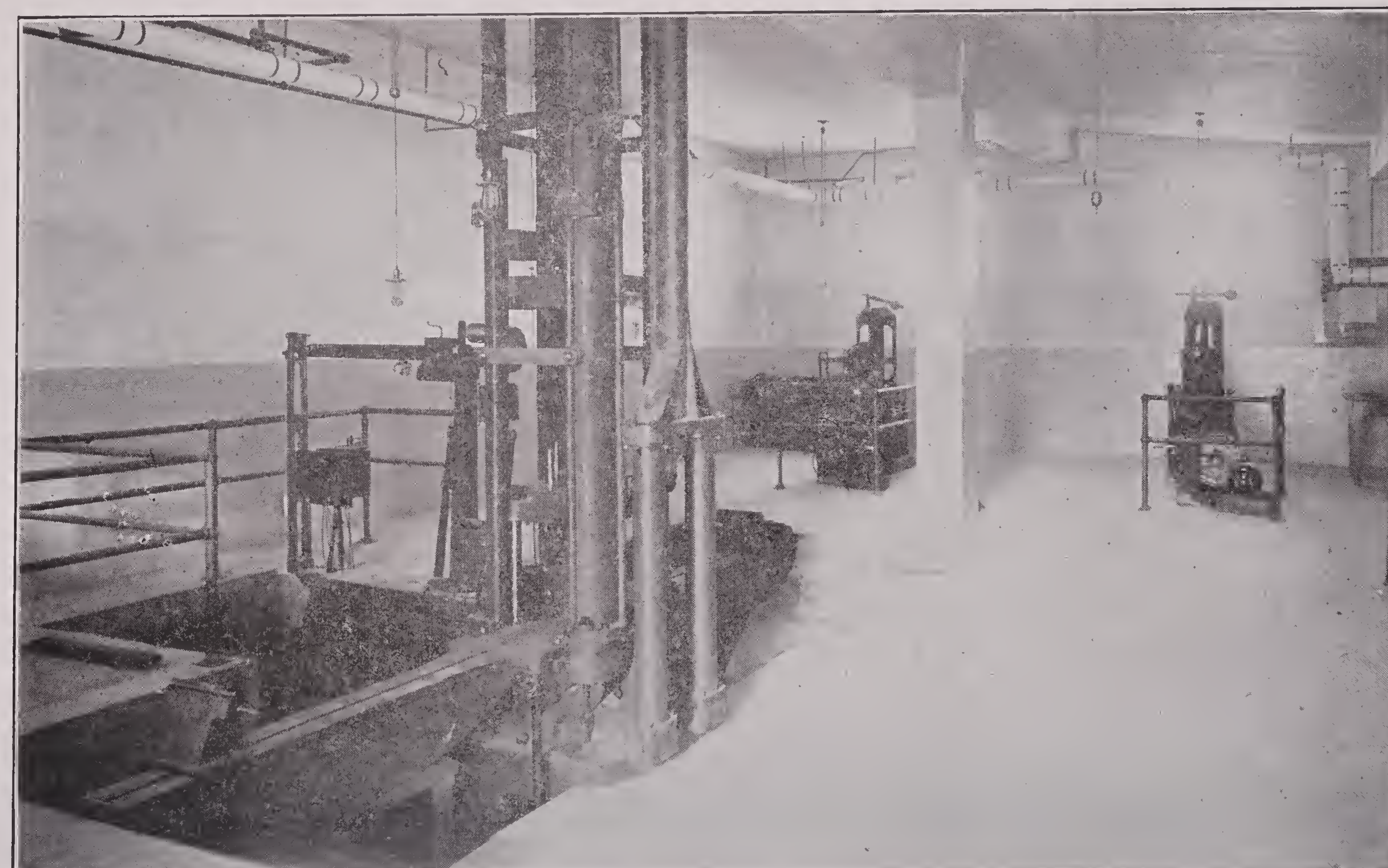
ROLLA, MISSOURI
1918



VIEW IN MATERIALS TESTING LABORATORY

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BULLETIN
OF THE
School of Mines and Metallurgy
UNIVERSITY OF MISSOURI
TECHNICAL SERIES

VOL. IV MAY, 1918 No. 4

INTRODUCTION

In the fall of 1913 in conjunction with the regular classwork in the cement testing laboratory of the Missouri School of Mines Prof. McCandliss undertook the study of the behavior of sand-blended cements. The results obtained were somewhat surprising, but owing to the limited facilities for carrying on the work, extended investigations were not made at that time. But in 1915 with the installation of the present well equipped laboratory for the testing of materials, it became feasible to carry out experimentation along more extensive lines. One of the problems to receive attention was the continued study of sand-blended cements.

The questions taken up were:

1. Can Portland Cement be blended with sand to produce a sand-blended cement having the same general physical properties as Portland Cement?
2. What amount of sand can be blended with Portland Cement without materially impairing the strength of the blended mixture?
3. In grinding cement clinker, does introducing sand with the clinker in a tube or ball mill facilitate fine grinding?

About three thousand test specimens for tension and compression have been prepared. In order that differences due to personal equation might not effect the results all of these specimens were prepared by Prof. McCandliss. It was planned to have the tests extend over a period of two years. The work was started in the fall of 1915 and carried on under the direction of Prof. McCandliss until he entered the military service in the spring of 1917. In the fall of 1917 the work was turned over to Prof. Armsby, who completed the tests in 1918.

A previous bulletin of this series (Vol. III, No. 3) gave the results obtained under question 1 for one year. This bulletin includes the matter therein presented, with the addition of the remaining tests for the complete series for two years.

The authors take pleasure in thanking the various cement companies for their co-operation in supplying the cement for these investigations. They are indebted to Mr.

H. A. Buehler, Director of the Missouri Bureau of Mines and Geology, for his assistance and advice, and to Messrs. B. L. Ashdown, E. C. Burkhart, C. E. Bardsley, T. C. Gerber, J. M. Morris, W. H. Reber, and J. R. Stubbins, students in the Missouri School of Mines and Metallurgy, for their cheerful assistance.

CALCAREOUS CEMENTS

The term cement has been applied: To any substance or composition which at one temperature or one degree of moisture is plastic and at another is tenacious; to adhesive mixtures employed to unite objects or parts of objects; to any material, capable of adhering to and uniting into a coherent mass, fragments of a substance not in itself adhesive; to any substance which by hardening causes objects between which it is applied to adhere firmly; to a tenacious infusible substance; to an adhesive or viscous substance; in general to any substance capable of uniting or tending to unite particles of matter into a compact whole. Lutes, glues, solders, gums, putty, mucilage, plasters, limes, hydraulic cements, and similar substances are all comprehended in this definition. Such a definition embraces a large variety of substances which differ one from another in composition, behavior, and importance, and have but few charactistics in common. Because of this, the term cement has become more or less generally restricted to the designation of that group or adhesives which is employed in the construction of engineering works. Cements of this kind bear a chemical relationship to each other, consisting as they do of mixtures which contain compounds of lime as their principal ingredient, in consequence whereof they are termed calcareous cements. Of these the most important by far is Portland Cement.

Portland Cement is a composition, the principal constituents of which are compounds of lime and clay. The abundance of these substances in nature, and the usefulness and cheapness of the cement combine to make it a universal material of construction.

The manufacture of Portland Cement is a highly specialized art, but in general it may be briefly outlined as follows: The clay and the lime are artificially mixed in predetermined proportions depending upon the purity of the materials. This mixture is reduced by grinding to a fine powder and the product roasted at a high temperature. This roasting causes the powder to undergo chemical and physical changes and the result is a semi-vitrified clinker. This clinker is commonly adjudged to be inert, or devoid of the properties of cements, but when reduced to an extremely

fine powder the finest particles possess the property of cements. Hence, in general, Portland Cement may be defined as the material obtained by finely pulverizing the clinker produced by calcining to incipient vitrification an intimate artificial admixture of properly proportioned argillaceous and calcareous substances.

BLENDED CEMENTS

Why it is that the particles of the cement clinker are inert when of appreciable size and that those of inappreciable size are active, has never been conclusively determined. Nor has the exact size or upper limits in size of the active particles been ascertained. It has, however, been conclusively demonstrated that any particle which will not pass through a standard No. 200 screen has no cementing properties and also that such particles as do pass through this screen are not necessarily active, but that a considerable percentage of them are practically inert. The present standard specifications for fineness of Portland Cement permit of 22% by weight to be retained on a standard No. 200 sieve. Hence it follows that commercial Portland Cement is a material composed of both active and inert particles, the latter being inactive on account of their physical coarseness and their amount being a large percentage of the cement. The desirability of continuing the grinding to reduce this percentage of inactive clinker has been a much discussed problem. But since the apparent increase in strength in the cement is not in proportion to the increased cost of manufacture, and also since the physical behavior of the cement so changes with continued grinding that it sets more rapidly, it appears that the economic limit of grinding cement clinker has been reached. On the other hand, the very fact that these inert particles are present in the cement in large amounts and that they are in reality dormant cement, needing only the energy to break them down to bring out their latent cementing qualities, suggests the presence of a considerable economic waste. If it is necessary to maintain the present graduation in the size of the particles in order to control the behavior of the cement, it is quite possible that some other substance less expensive than cement clinker can be used for the large size particles. In other words, if it is necessary to have these inert particles present in the cement, there are other inert substances in nature, which might be used as a substitute for the inert clinker particles in case the substitution could be made, thus permitting the further reduction of the clinker into active cement. It is assumed that such a substitution can

be accomplished and it is here proposed to study the effect of such procedure.

The product obtained by mixing Portland Cement with some other finely pulverized substance in a dry condition before being used in mortar or concrete, is commonly termed "blended cement." The substance which is mixed with the Portland Cement is designated the "blending material, or the blend." This latter may be either entirely inactive as a cement or may possess cementing qualities.

The blending of Portland Cement is no innovation as the practice probably made its first appearance in the early nineties. But, owing to the rapid development of the Portland Cement industry with the accompanying reduction in the cost of the product, the practice has been largely discontinued. These cements were manufactured in general by merely mixing the ingredients, Portland Cement and the blend, in a ball or tube mill, no especial effort being made to continue the grinding of the cement. This product was marketed under various trade names such as "silica cement," "sand cement," "tufa cement," etc., the name depending largely upon the nature of the blending material used. While these cements have no importance in present construction as a general proposition, still the economic advantages derived from such methods have not passed into absolute obscurity. Several noteworthy instances might be cited where large constructions have been carried on in which blended cement has been used with satisfaction, whereby considerable economies have been effected. Among the more recent and important of these are the works of the U. S. Reclamation Service and the Los Angeles Aqueduct Commission. In these undertakings the justification for using blended cements has been based largely upon the excessive transporation charges due to the remoteness of the projects from industrial centers. While this condition existed, it is unfortunate that thereby the inference has been given that otherwise blended cements would not have been used, for it is quite possible that in creating this impression an injustice has been done to a worthy practice. The theory has also been advanced that only materials containing active or colloidal silica are suitable for blending Portland Cement. This, of course, excludes quartz sand, and here again it is possible that an erroneous notion is conveyed, for, although it is not proposed to discuss the relative merits of quartz sand as a blend, yet an endeavor will be made to show that it can be used satisfactorily for this purpose.

MATERIALS

In selecting the cements for use in this investigation, an effort was made to choose such brands of Portland Cement as would give some range in the character of the component raw ingredients. Three commercial Portland Cements were used, viz: Atlas, Lehigh, and Red Ring. The composition of the Atlas Portland Cement is Mississippian Limestone and Pennsylvanian shale; that of the Lehigh Portland Cement is hard Mitchell (Mississippian) limestone and shale; and that of the Red Ring Portland Cement, Mississippian limestone, Pennsylvanian shale, together with Loess clay. There is no special difference in the methods used in manufacturing these three cements.

The blending material used was a natural quartz sand from Ottawa, Illinois. It was supplied by the Ottawa Silica Company and is marketed under the trade name of "Banding Sand." This sand is quite fine but well graded and with but slight sifting was found to conform closely in gradation to the coarser particles in the Portland Cement, and was therefore a suitable substitute for them in making the blended cements.

For mortar specimens, standard Ottawa sand was used.

Each of these materials was received at the laboratory in good condition and stored in suitable containers. The Portland Cements were each passed through a No. 20 sieve before storing, to insure uniformity throughout the samples and to remove large lumps.

SCOPE OF TESTS

Two separate series of tests are included in this report, which are called, for convenience, Series I and Series II. These two series will be taken up separately.

SERIES ONE

DESCRIPTION

Series I comprises the tests originally outlined for the investigation, and comprises three Divisons, called A, B, and C. These three Divisions are made up in exactly the same manner, but using different brands of cement; Division A using Atlas Portland Cement, Division B using Lehigh Portland Cement, and Division C using Red Ring Portland Cement. A Division consists of the cement itself and four blended cements. These blended cements were composed of (1) such part of the Portland Cement as easily passed a No. 200 sieve, and (2) quartz sand, all of which passed a No. 65 seive, and about seventeen per cent of which passed a standard No. 200 seive. These blended cements,

for convenience of identification, are designated A_{10}, A_{20}, A_{30}, and A_{40}, the numerals indicating the percentage by weight of sand present in the blended cement.

PURPOSE

The purpose in view in making up this series was to study the behavior of blended cements made up in such a way as to approach as closely as possible to the same range in gradation in size of particles as occurs in the original Portland Cement. In other words, it was proposed to remove from the Portland Cement the large, inert particles and to substitute for them other inert particles of about the same size. No accurate means were devised for determining the precise amount of the particles removed from the Portland Cement, and therefore several combinations were used which it was thought would give sufficient range to obtain a satisfactory comparison. The end desired was to ascertain whether it is essential in Portland Cement, in order to maintain its present physical characteristics, to have unpulverized clinker for the coarser particles or whether a fine sand would serve the purpose equally well, sand being used because of its having no cementing tendencies, and because of its abundance in nature.

PROCEDURE

Coarse particles were removed from the Portland Cements by screening through a standard No. 200 sieve and those of the banding sand by screening through a No. 65 sieve. Enough of each of these materials was then weighed out to produce 500 or 1,000 grams of blended cement in the proportion desired, 500 grams being used in making the test specimens for tension and 1,000 grams the specimens for compression. The sand and cement were then mixed by pasing the mixture through a No. 35 screen six times. The resulting blended cement was uniform in color and had every indication of being well combined. It was noted, however, that the materials separated slightly if the containers were dropped lightly upon the table a few times, a fine rim of sand appearing about the base of the cone of the cement. Therefore extreme care was taken not to disturb the blended cements after they were made until they were formed into test specimens.

Chemical analyses were made of each of the materials, and on each cement of each Division the following physical tests were made: (a) Neat tension, (b) mortar tension (c) neat compression, (d) mortar compression, (e) normal consistency, (f) time of setting, (g) constancy of volume (normal and accelerated tests), (h) fineness and sieve analysis and (i) specific gravity. The methods for testing cement

recommended by the American Society of Civil Engineers (See Transactions Vol. 75) were followed but with the following exceptions: A sieve analysis was made of each of the cements. The percentage of water used in making mortar specimens was increased one per cent above the recommended values. Sufficient specimens for neat and mortar tension and compression were made to permit of making tests at intervals up to and including two years, the average of three breaks constituting a test.

Compressive test specimens were cylinders two inches in diameter and two inches high. They were made in wooden moulds which had been especially prepared for the purpose. These moulds were twelve inches long, four inches wide, and two inches high, and were made in two sections. The sections were held together with dowels and bolts and were provided with three two-inch holes symmetrically placed on the axis of the block. Poplar wood was used, and the moulds were finished and painted and, as an added precaution against absorption of the water from the specimens, the moulds were greased with hard engine oil each time before being used. The moulds were satisfactory, and good specimens were obtained. No tamping device was used, all moulds being filled by hand.

Compression tests were made with two-screw testing machine of the Riehle type, having a capacity of 50,000 pounds. Each specimen upon being removed from the storage tank was calibrated and weighed to ascertain the relative density. The specimens were at once mounted in the machine on a hemispherical bearing plate and imbedded in plaster of Paris. After centering the specimen in the machine, a light initial load was applied. After the plaster had hardened, continuous load was applied, the moving head of the testing machine travelling at a rate of about .06 inch per minute until failure. The load when first crack appeared in the specimen, as well as the ultimate load, was recorded. These loads were reduced to unit stresses for comparison.

Each of the blended cements was put through the same tests as the Portland Cements except that the chemical analysis and specific gravities were computed and not determined experimentally and no determinations for fineness or sieve analysis were made. In preparing the blended cements each test was prepared separately, only enough of the materials being laid out at a time to make three test specimens.

RESULTS OF TESTS

The complete detailed results of all tests made in this investigation are tabulated and appended to this report in Appendix B. For ease and convenience in reading the re-

sults, Appendix A has been prepared, giving only the final average results as they appear in the tables of Appendix B. The tables of Appendix A were used in plotting the curve sheets which follow in the discussion. These curve sheets were prepared to facilitate the interpretation of the tabulated results. Tables of comparative strengths have also been prepared, and these are also included with the discussion which follows.

(A) Neat Cement in Tension.

On curve sheet No. 1 are plotted the results obtained from tension tests of Atlas Portland Cement "A" and the blended cements made from the same. (See Table A, Appendix A). It will be noted from the curves here shown that each of these cements meets the requirements for neat cement in tension of the standard specifications of the American Society for Testing Materials (1916), which are 175; 500 and 600 pounds at twenty-four hours, seven days, and twenty-eight days respectively. In each case the maximum strength is attained within the first twelve weeks. Cement A, the Portland Cement, attains the greatest maximum strength. For comparison of relative strengths, Table I has been compiled. It is intended to show in this table the relative strengths of the five cements at the various ages of testing, the values one to five being assigned to the various relative strengths in their order of importance, 1 indicating the cement developing maximum strength and 5 indicating the one developing the minimum strength at the same period.

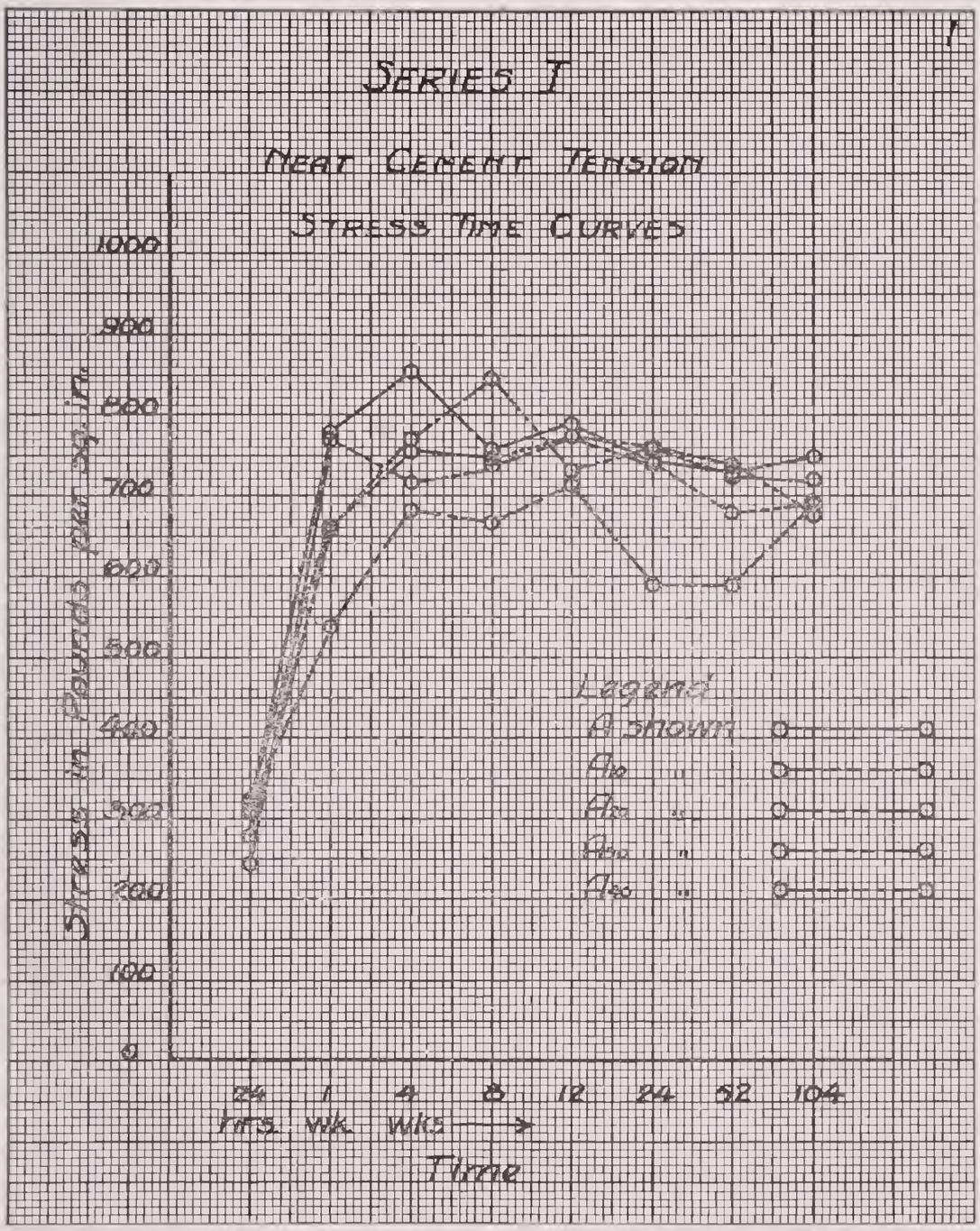
TABLE I

Series I

RELATIVE STRENGTHS

Age of test in weeks	(24 hr.)	1	4	8	12	24	52	104
A	1	1	1	2	1	3	3	1
A_{10}	2	5	5	5	5	5	5	4
A_{20}	5	2	4	4	3	4	4	3
A_{30}	4	3	2	1	4	2	1	5
A_{40}	3	4	3	3	2	1	2	2

From Table I it is seen that cement A ranges first in point of strength except for the 24- and 52-week tests, in which it is outranked by cements A_{30} and A_{40}. A_{10} appears to be the weakest throughout the run of the tests, A_{20} next with A_{30} and A_{40} only slightly inferior to A after 12 weeks. From Curve Sheet 1 it appears that A_{30} and A_{40} attain their strength somewhat more slowly than A, but are nearly as strong after 12 weeks.


I
Series T
Neat Cement Tension
Stress Time Curves
Stress in Pounds per Sq. In.
1000
900
800
700
600
500
400
300
200
100
0
24 hrs.
1 wk.
4 wks.
8
12
24
52
104
Time
Legend
A shown
A10 "
A20 "
A30 "
A40 "

On Curve Sheet 2 are plotted the results obtained from tests of Lehigh Portland Cement, "B", and the blended cements from the same. (See Table A, Appendix A). Each of these cements meets the requirements of the standard specifications of the American Society for Testing Materials (1916). It is to be noted also that in each case the maximum strength is attained within the first twelve weeks, Cement "B" attaining the greatest maximum strength. Table II is similar to Table I.

TABLE II

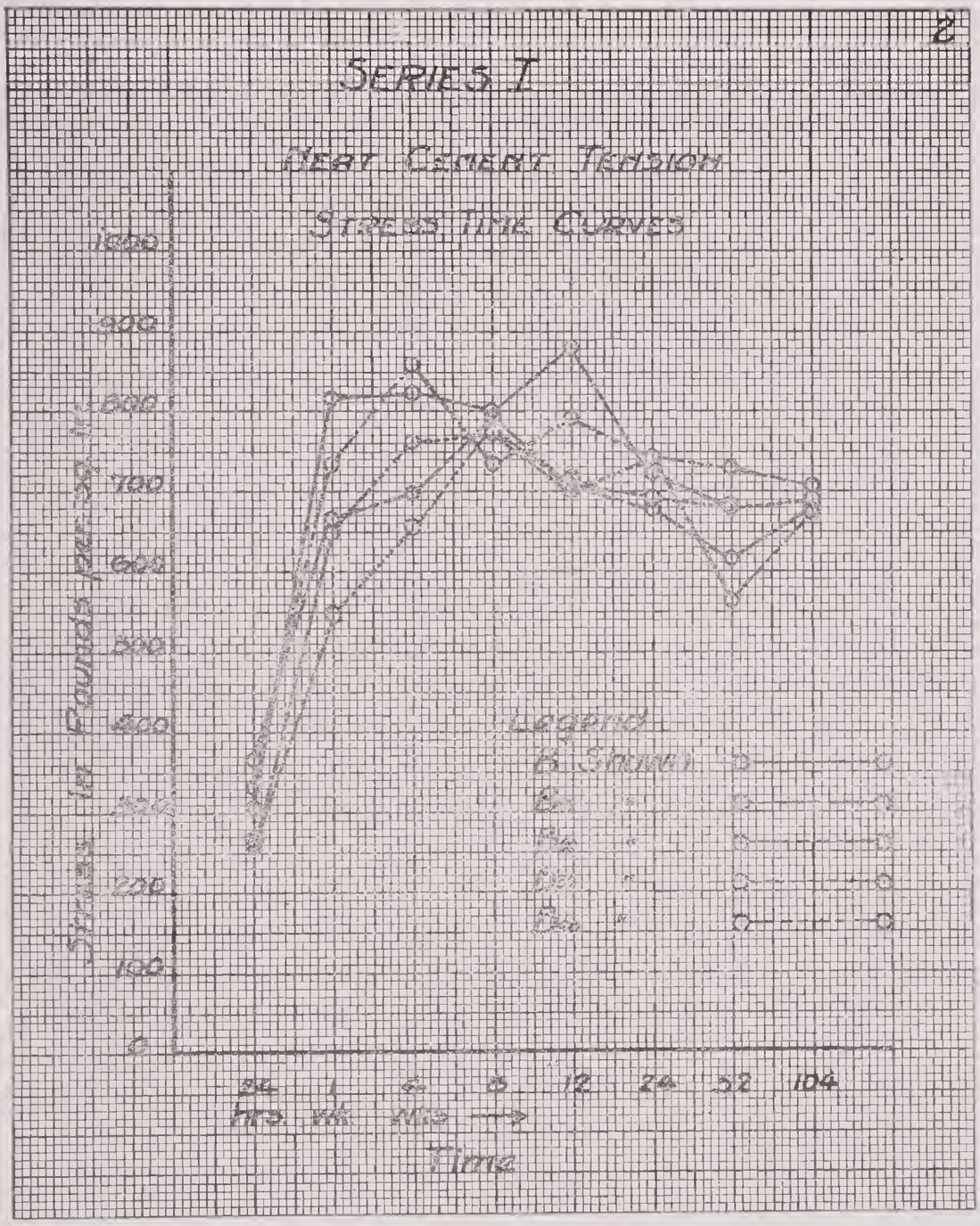
Series I

RELATIVE STRENGTHS

Age of test in weeks	(24 hr.)	1	4	8	12	24	52
B	3	1	2	1	1	3	3
B_{10}	1	3	4	2	4	5	4
B_{20}	2	2	1	5	2	1	5
B_{30}	5	4	3	3	3	2	1
B_{40}	4	5	5	4	5	4	2

From Table II Cement B seems to rank first in relative strength up to and including twelve weeks. Over this period of time B_{20} ranks second, B_{10} third; B_{30}, fourth; and B_{40}, fifth. This relationship is not pronounced, however, there being several conflicts. It is quite apparent, however, that after twelve weeks B_{30} and B_{40} increase in relative importance and are equal or superior to B, while B_{10} and B_{20} make a relative less favorable showing. From Curve Sheet 2 it is seen that B_{30} develops the most uniform strength throughout the entire period of testing.

Unfortunately the specimens for the 104-week tests were lost, so no results can be given for this age.


2
SERIES I
NEAT CEMENT TENSION
STRESS TIME CURVES
1600
1400
1200
1000
800
600
400
200
0
24 HRS.
1 WK.
4
8
12
24
32
104
Time

On Curve Sheet 3 are plotted the results obtained from testing Red Ring Portland Cement "C" and blended cements made from the same, in tension. (See Table A, Appendix A). Each of these cements meets the requirements of the standard specifications of the American Society for Testing Materials (1916) In each case the maximum strength was attained in twelve weeks. Cement "C" attains the greatest maximum strength. Table III is similar to Table I.

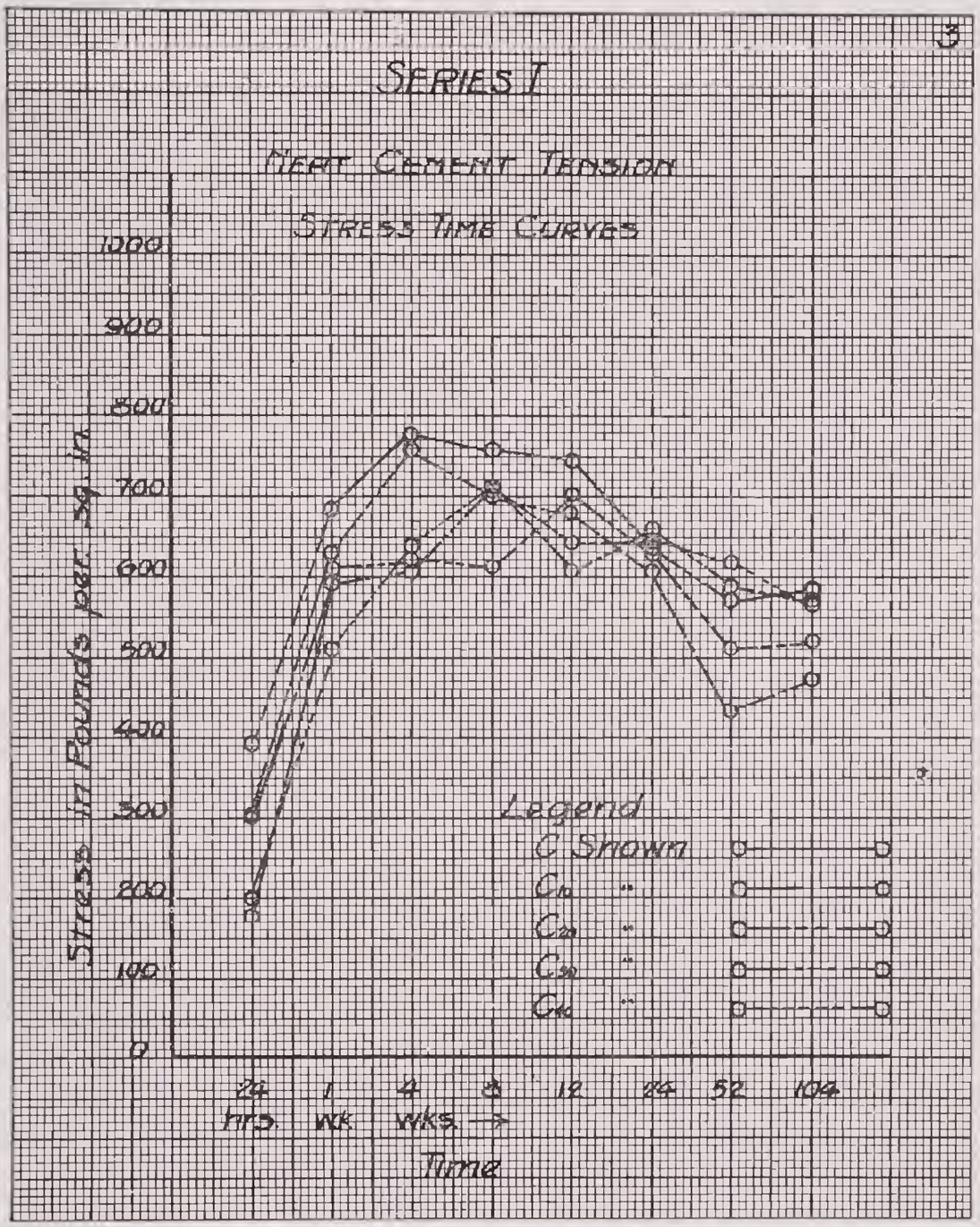
TABLE III

Series I

RELATIVE STRENGTHS

Age of test in weeks	(24 hr.)	1	4	8	12	24	52	104
C	1	1	1	1	1	3	3	1
C_{10}	3	2	2	2	3	5	5	5
C_{20}	2	3	4	5	2	4	4	4
C_{30}	5	4	5	4	5	1	2	2
C_{40}	4	5	3	3	4	2	1	3

From Table III it is seen that the cements in this Division follow practically the same variations in relative strength as those in the "A" Division, with C ranking first, C_{30} and C_{40} only slightly inferior, C_{20} ranking fourth and C_{10} last.


3
SERIES I
NEAT CEMENT TENSION
STRESS TIME CURVES
1000
900
800
700
600
500
400
300
200
100
0
Stress in pounds per sq. in.
24 hrs.
1 wk.
4 wks.
8
12
24
52
104
Time
Legend
C Shown
C7d "
C28d "
C3m "
C6m "

On Curve Sheet 4 are plotted the results obtained by averaging the corresponding tests plotted on Curve Sheets I, II, and III. (See Table A "Average of averages," Appendix A). From this Curve Sheet it is seen that in each case the requirements of the standard specifications of the American Society for Testing Materials (1916) are satisfied. The maximum tensile strength is attained in each case in the first twelve weeks. The average of the commercial Portland Cements attains the greatest maximum strength. Table IV is similar to Table I.

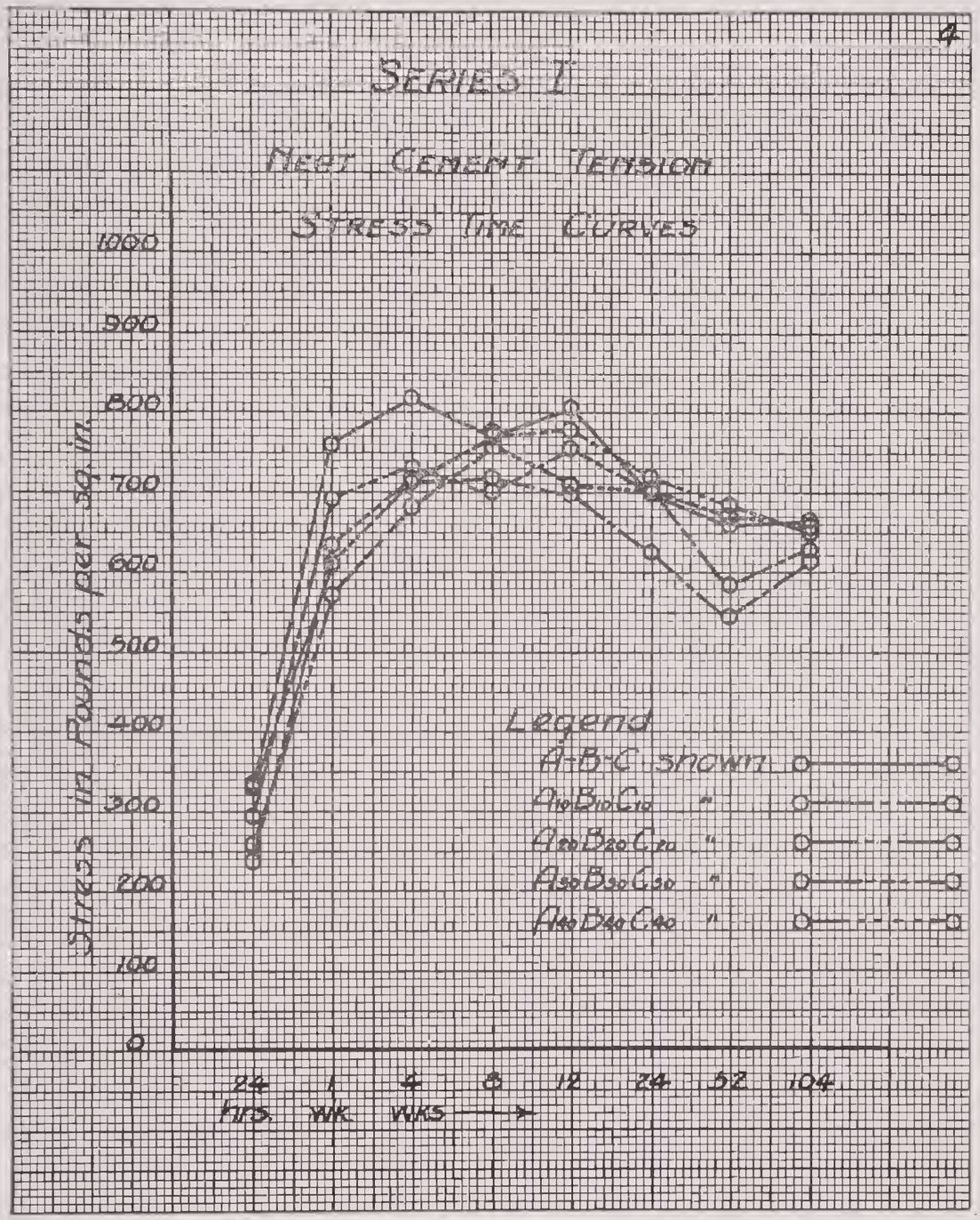
TABLE IV

Series I

RELATIVE STRENGTHS

Age of test in weeks	(24 hr.)	1	4	8	12	24	52	104
A-B-C	1	1	1	1	1	3	3	1
A_{10} B_{10} C_{10}	2	4	3	4	5	5	5	5
A_{20} B_{20} C_{20}	3	2	2	5	3	4	4	4
A_{30} B_{30} C_{30}	5	3	3	2	2	1	1	3
A_{40} B_{40} C_{40}	4	5	5	3	4	2	2	2

From Table IV it is seen that the "Average of averages" curves conform to the same variations as the single curves do, with the same relative ranks for the different blends. It is to be noted in all these curves that the changes in relative rank in the 24- and 52-week tests are not due to increased strengths in the cements containing 30 and 40 per cent blend, but rather to decreasing strengths in the others. The average of the cements with a blend of 45 per cent develops a strength at the age of about four weeks. This strength it retains quite consistently as the age increases during the fifty-two weeks of test. The maximum range in variation during this period is about 70 pounds or about ten per cent of the average strength developed. It is interesting to note that the average variation or range in the strengths at the successive periods of testing is about 120 pounds. From a comparison of Curves A, B, and C from Curve Sheets 1, 2, 3, it is seen that the average variation in strength of these commercial cements is about 108 pounds. From this observation, it would seem that had commercial Portland Cements been tested instead of the blended cements and in all other respects had the results been averaged as


4
SERIES I
NEAT CEMENT TENSION
STRESS TIME CURVES
STRESS in Pounds per Sq. In.
1000
900
800
700
600
500
400
300
200
100
0
24 HRS.
1 WK
4 WKS
8
12
24
52
104
Legend
A-B-C shown
A10B10C10 "
A20B20C20 "
A30B30C30 "
A40B40C40 "

has been done on Curve Sheet 4, there would have been developed a variation in the strengths practically as great as shown here. In other words there seems to be but little more variation in the strength shown on curve sheet 4 than might reasonably be expected from that number of commercial Portland Cements, and that in the matter of neat cement in tension within the scope of this investigation the blended cements compare favorably with commercial Portland Cements.

(B) Cement Mortar in Tension.

On Curve Sheet 5 are plotted the results of tests for tension of 1 to 3 mortar specimens of Atlas Portland Cement A and blended cements of the same. (See Table B, Appendix A). It will be noted that with the exception of Cement A each of the cements satisfied the requirements of the standard specifications of the American Society for Testing Materials for mortar briquettes in tension, which for 1916 are 200 and 275 pounds per square inch at the ages of seven and twenty-eight days respectively. The specifications for 1917 require 300 pounds per square inch to be developed at the age of twenty-eight days. In each case the maximum strength is attained in the first twelve weeks. Cement A attains the least maximum strength. Cement A_{40} attained a strength of about 350 pounds at four weeks and maintained this strength throughout the remainder of the period. The maximum variation after the first four weeks was about 300 pounds. For the comparison of relative strengths Table V has been prepared. It is similar to Table I.

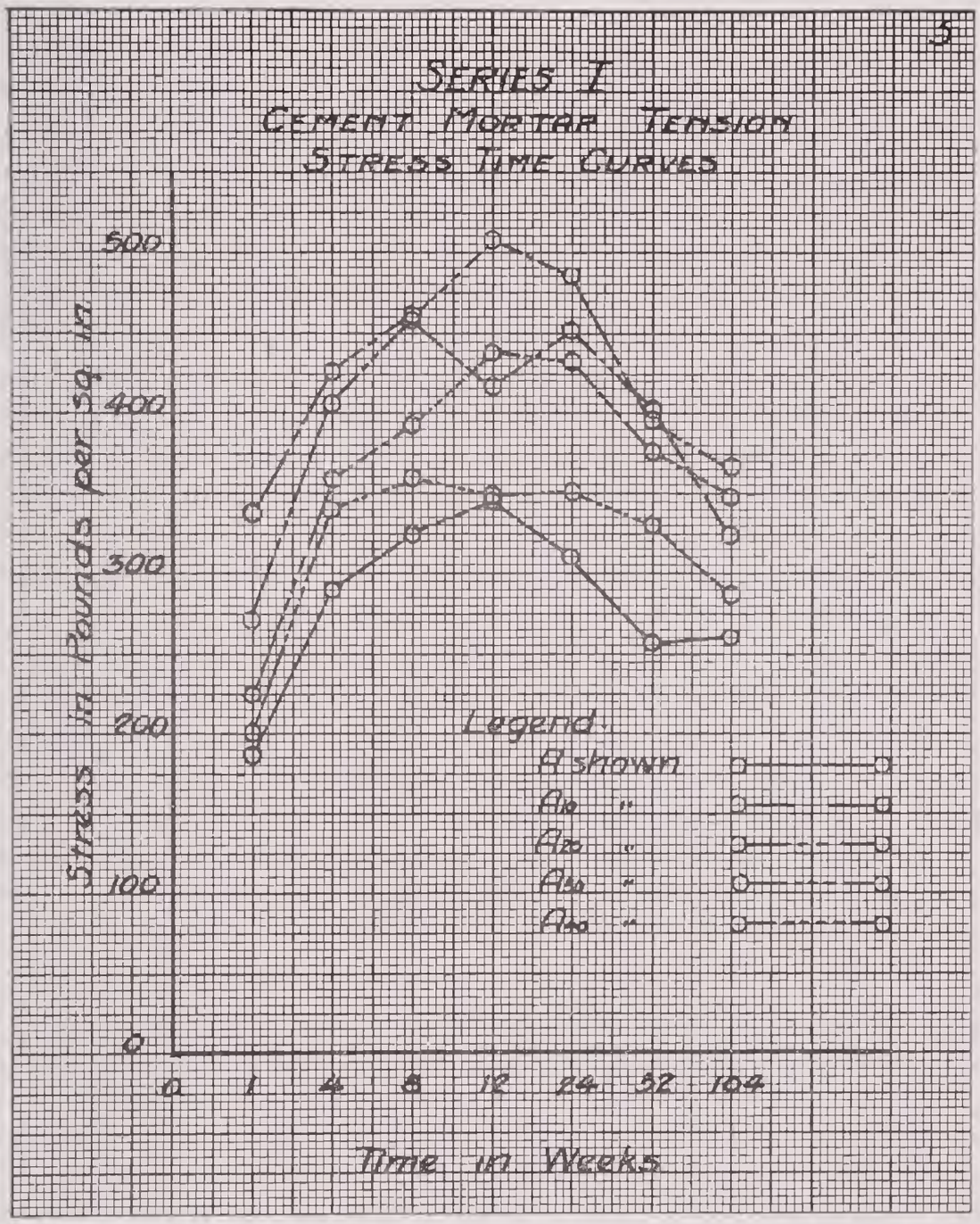
TABLE V

Series I

RELATIVE STRENGTHS

Age of test in weeks	1	4	8	12	24	52	104
A	5	5	5	5	5	5	5
A_{10}	1	1	1	1	1	2	1
A_{20}	2	2	2	3	2	1	3
A_{30}	3	3	3	2	3	3	2
A_{40}	4	4	4	4	4	4	4

From Table V it is seen that in relative strength A_{10} ranks first; A_{20}, second; A_{30}, third; A_{40}, fourth, while the commercial Portland Cement "A" ranks last throughout the entire period of testing.


5
SERIES I
CEMENT MORTAR TENSION
STRESS TIME CURVES
Stress in Pounds per Sq. In.
500
400
300
200
100
0
0
1
4
8
12
24
52
104
Time in Weeks
Legend.
A shown
A10 "
A20 "
A30 "
A40 "

On Curve Sheet 6 are plotted the results of tests for tension of 1 to 3 mortar specimens of Lehigh Portland Cement "B", and blended cements of the same. (See Table B, Appendix A). It will be noted that each of these cements meets the requirements of the standard specifications of the American Society for Testing Materials (1916 or 1917), for mortar briquettes in tension. Cements B and B_{40} are considered as conforming with the 1917 specifications at an age of one week, with strengths of 197 and 194 pounds per square inch, respectively, in view of their showing at the age of four weeks. Maximum strengths are attained within the first twelve weeks except in the case of B_{10} which shows a maximum strength at fifty-two weeks. Table VI is similar to Table I.

TABLE VI

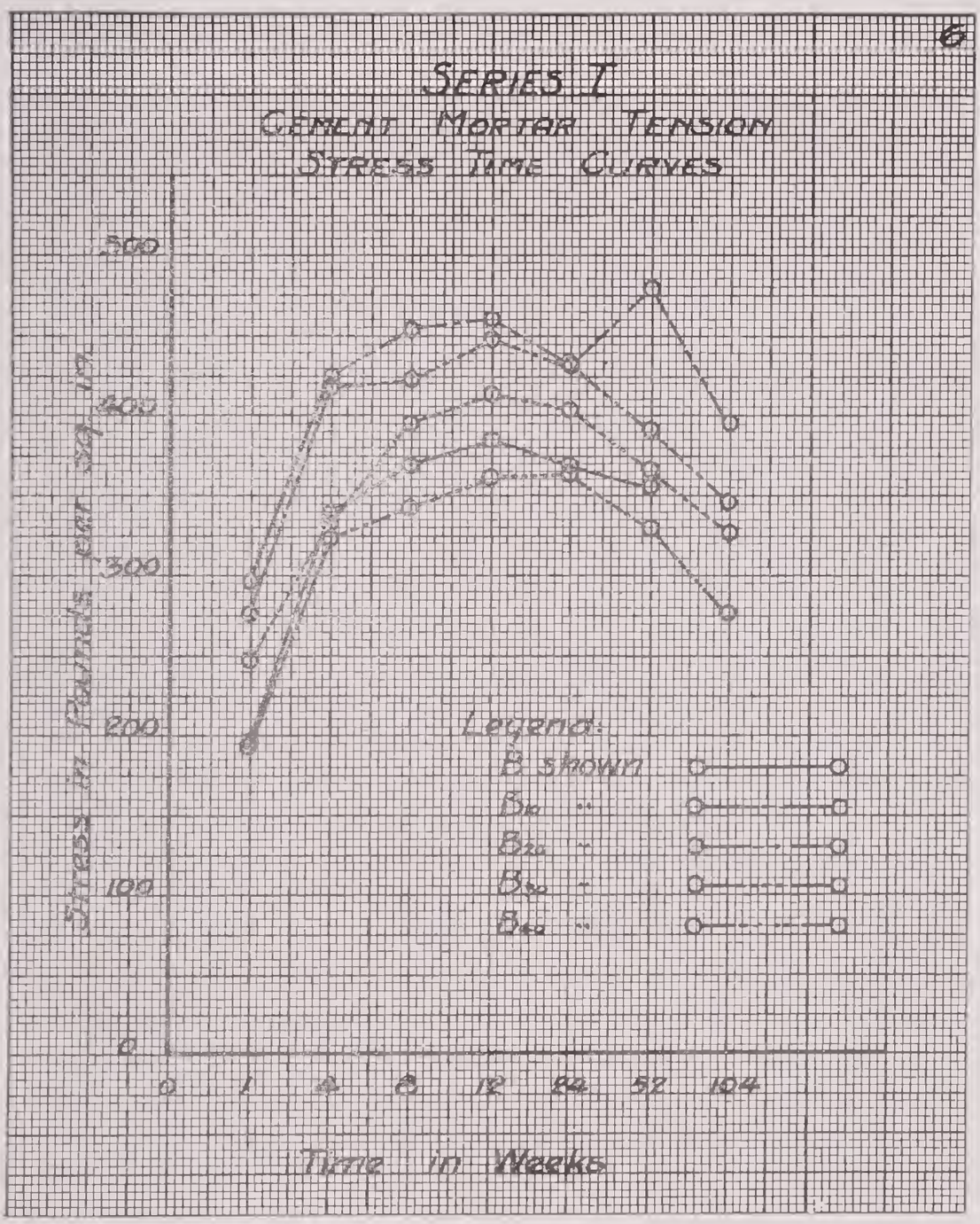
Series I

RELATIVE STRENGTHS

Age of test in weeks	1	4	8	12	24	52
B	4	4	4	4	4	4
B_{10}	1	1	1	1	1	1
B_{20}	2	2	2	2	2	2
B_{30}	3	3	3	3	3	3
B_{40}	5	5	5	5	5	5

By reference to Table VI it is seen that B_{10} easily ranks first in relative strength throughout the entire period of tension; B_{20}, second; B_{30}, third; "B", fourth; and B_{40}, fifth.

Unfortunately the specimens for the 104-week tests were lost, so no results can be given for this age.


6
SERIES I
CEMENT MORTAR TENSION
STRESS TIME CURVES
Stress in Pounds per Sq. In.
500
400
300
200
100
0
0
1
4
8
12
24
52
104
Time in Weeks
Legend:
B shown
B10 "
B20 "
B30 "
B40 "

On Curve Sheet 7 are plotted the results of the tests for tension of 1 to 3 mortar specimens of Red Ring Portland Cement "C" and blended cements of the same. (See Table B, Appendix A). These results seem to be less uniform than those shown on the two previous curve sheets. It will be noted, however, that each of these cements satisfactorily meets the requirements of the standard specifications of the American Society for Testing Materials of mortar briquettes in tension (1916). In each case the maximum strength is attained within the first twelve-week period. Table VII is similar to Table V.

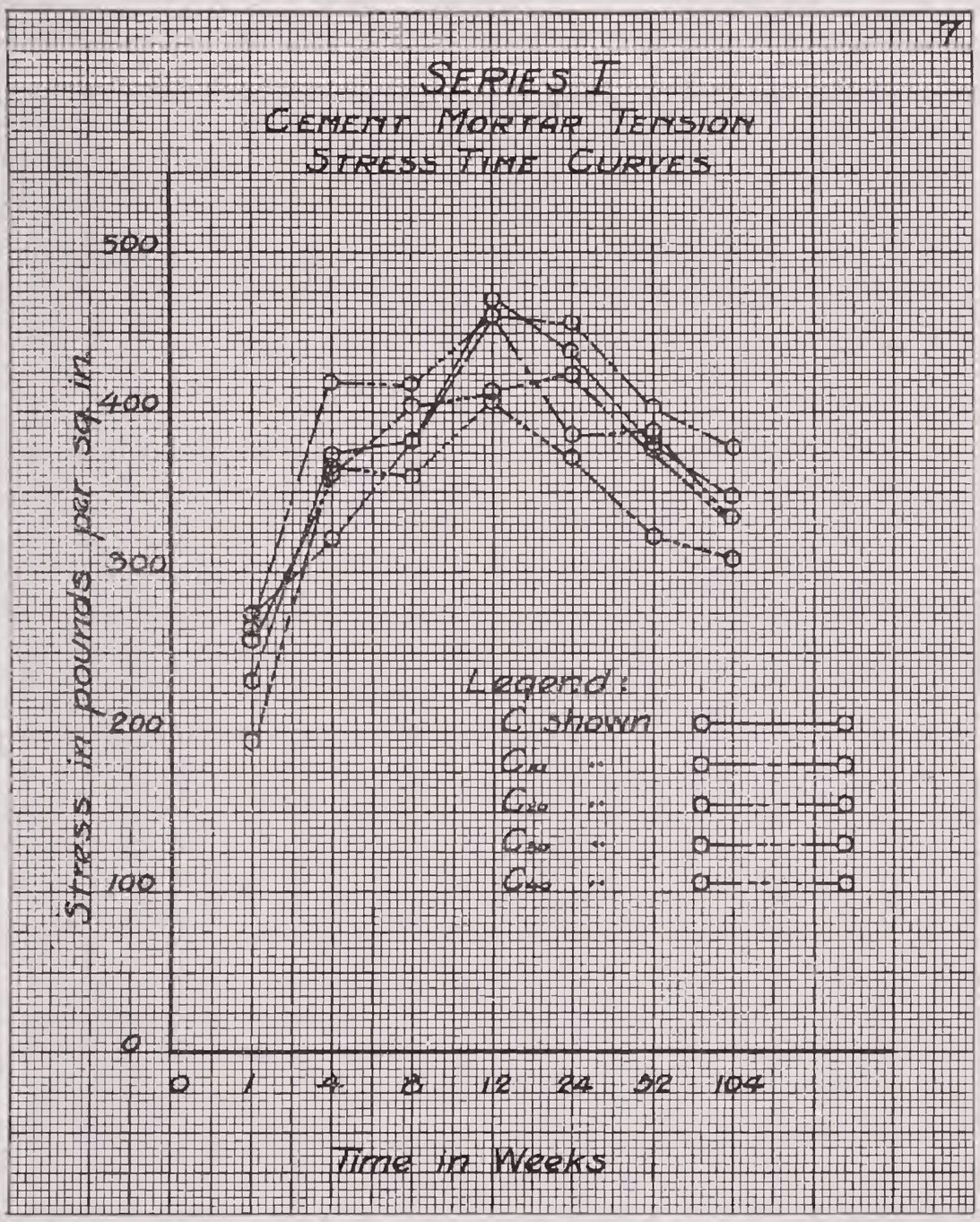
TABLE VII

Series I

RELATIVE STRENGTHS

Age of test in weeks	1	4	8	12	24	52	104
C	4	2	3	1	2	3	2
C_{10}	1	4	3	1	1	1	1
C_{20}	2	1	1	3	4	2	3
C_{30}	3	5	2	4	3	4	3
C_{40}	5	3	5	5	5	5	-5

From Table VII, while it is more difficult to fix relative strength than in some of the previous cases, it is apparent that C_{40} should be classified last or fifth in strength; C_{30} should probably receive fourth place; of the remainder, the classification is more difficult and less well defined, but the classification suggested places C_{10} first, C_{20} second, and C third. It will be noted that this classification corresponds to the relative strengths developed at 1, 12, and 52 weeks, respectively.


7
SERIES I
CEMENT MORTAR TENSION
STRESS TIME CURVES
500
400
300
200
100
0
Stress in pounds per sq. in.
0
1
4
8
12
24
52
104
Time in Weeks
Legend:
C shown
C₁₀
C₂₀
C₃₀
C₄₀

The values plotted on Curve Sheet 8 represent the results obtained by averaging corresponding values from those plotted on Curve Sheets 5, 6, and 7. (See Table B, "Average of averages," Appendix A). The results obtained from averaging A, B, and C, the three specimens of commercial cement mortar in tension, should represent approximately the behavior of an average commercial Portland Cement. This curve sheet corresponds with Curve Sheet 4 except that the latter is for neat cement in tension. It will be noted here that each of these cements satisfies the requirements of the standard specifications of the American Society for Testing Materials (1916) for cement mortar in tension. Each of the cements attain maximum strength during the first twelve weeks. The differences in strength at any age is not radical, 100 pounds being an approximate average range in strength. For ascertaining relative strengths Table VIII is shown which is similar to Table I.

TABLE VIII

Series I

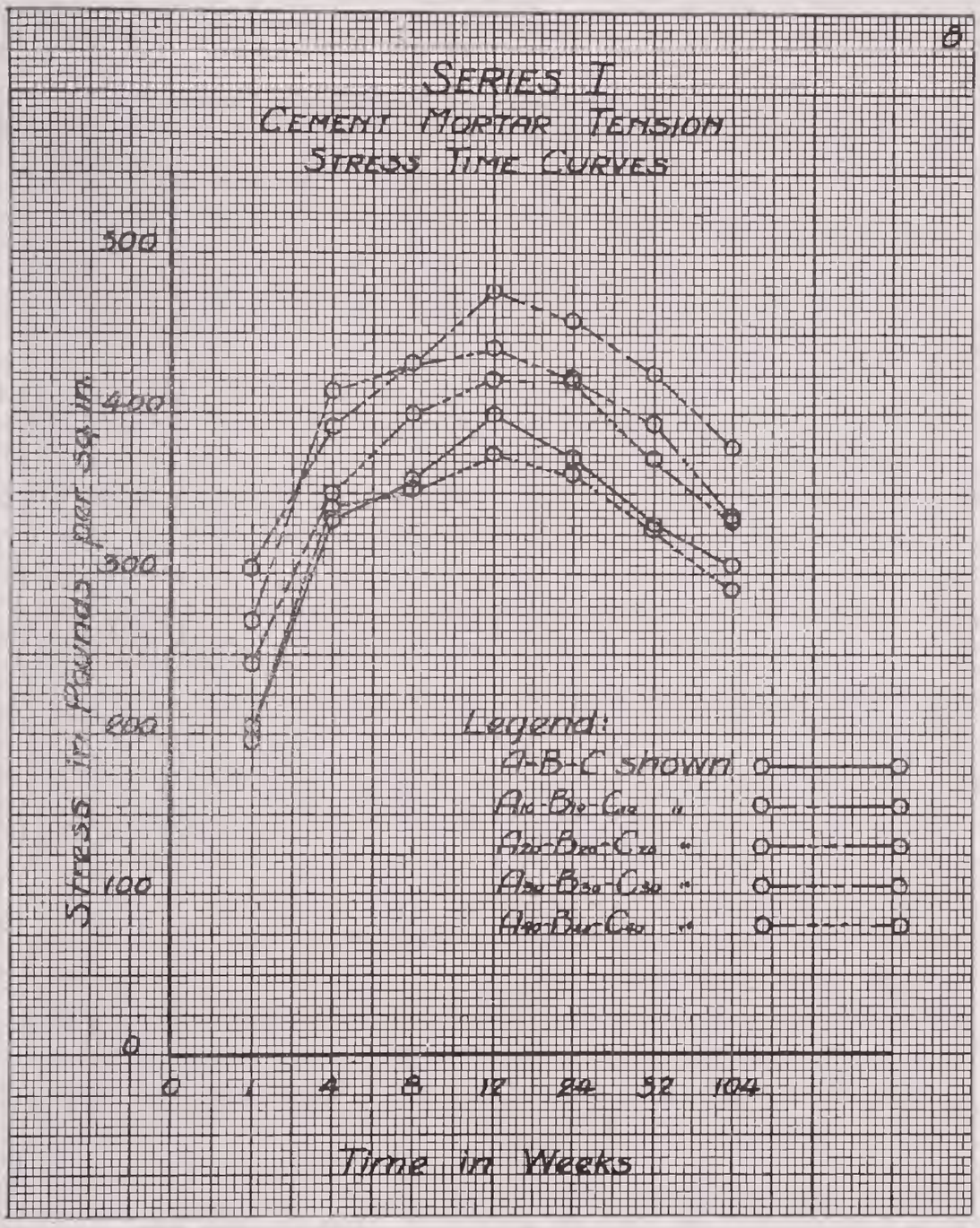
RELATIVE STRENGTHS

Age of test in weeks	1	4	8	12	24	52	104
A B C	4	5	4	4	4	4	4
A_{10} B_{10} C_{10}	1	2	1	1	1	1	1
A_{20} B_{20} C_{20}	2	1	1	2	2	2	3
A_{30} B_{30} C_{30}	3	3	3	3	3	3	2
A_{40} B_{40} C_{40}	5	4	5	5	5	5	5

Table VIII gives the following classifications: A_{10},B_{10}, C_{10}, first; A_{20}, B_{20}, C_{20} second; A_{30}, B_{30}, C_{30} third; A, B, C fourth; and A_{40}, B_{40}, C_{40}, fifth. By reference to Curve Sheet 8, it is seen that there is but little difference in strength in A, B, C and A_{40}, B_{40}, C_{40}. In the case of cement mortar in tension, the results of these investigations show that the blended cements are equal or superior to Portland Cement.

(C) Neat Cement In Compression.

The results obtained from each cement in compression cannot be considered satisfactory in all respects. They are apparently inconsistent and contradictory. Tests of a cement made at different time periods seem to follow no general law. In some cases, maximum strengths occur with the oldest tests; in others, at the early test periods. The


SERIES I
CEMENT MORTAR TENSION
STRESS TIME CURVES
500
400
300
200
100
0
Stress in pounds per sq. in.
0
1
4
8
12
22
52
104
Time in Weeks
Legend:
A-B-C shown
A10-B10-C10 "
A20-B20-C20 "
A30-B30-C30 "
A40-B40-C40 "

cause of this eccentricity in results is not apparent. Extreme care was maintained throughout the entire period of experimentation in order to secure uniform conditions, and it is felt that all specimens were treated substantially alike. If it is characteristic of neat cement in compression to show no more uniformity in the results than those here obtained, there seem to be no data available to establish the fact. It is significant, however, that the results obtained from the Portland Cements are no more consistent than those gotten from the blended cements, and in no single instance do the results obtained show uniformity of behavior throughout. The like blended cements of the three commercial Portlands show but slight similarity and the commercial Portlands differ one from the other in behavior. The results obtained are submitted without further apology, but it is hoped that further experimentation will afford a basis for a satisfactory explanation of the behavior of these cements in compression. Attention is called to the fact that this is not a standard test, and in consequence there is no specification to be satisfied, but none of all of these tests, with but a single slight exception, falls below the limit of safety for most large buildings, that is 5000 pounds per square inch.

On Curve Sheet 9 are plotted the results obtained from testing Atlas Portland Cement "A" and blended cements of the same in compression (neat). (See Table C, Appendix A.) As has been noted, there seems to be no uniformity in the behavior of the various curves. Cement "A" shows a substantial increase in strength throughout the duration of the test, and it would appear that the maximum strength which this cement may attain has not been reached. Unfortunately the 104-week specimens were lost, so that it can not be stated as a fact, but it is probable that the strength developed at 52 weeks would not be greatly increased at later periods.

Cement A_{10} follows closely cement A within the first 24 weeks, there being but slight preference between them. The unusual drop experienced in the 52- and 104-week tests of A_{10} is one of the surprises encountered.

Cement A_{20} develops no unusual characteristics, the average result throughout the entire period being fairly consistent. The same may be observed of A_{30}. The most unusual development in the tests of A_{40} seems to be the relatively low strength at 52 weeks.

Table IX is similar to the previous tables, used in comparing relative strength at the various time-intervals, numerals 1 - 5 being assigned to the highest and lowest strengths.

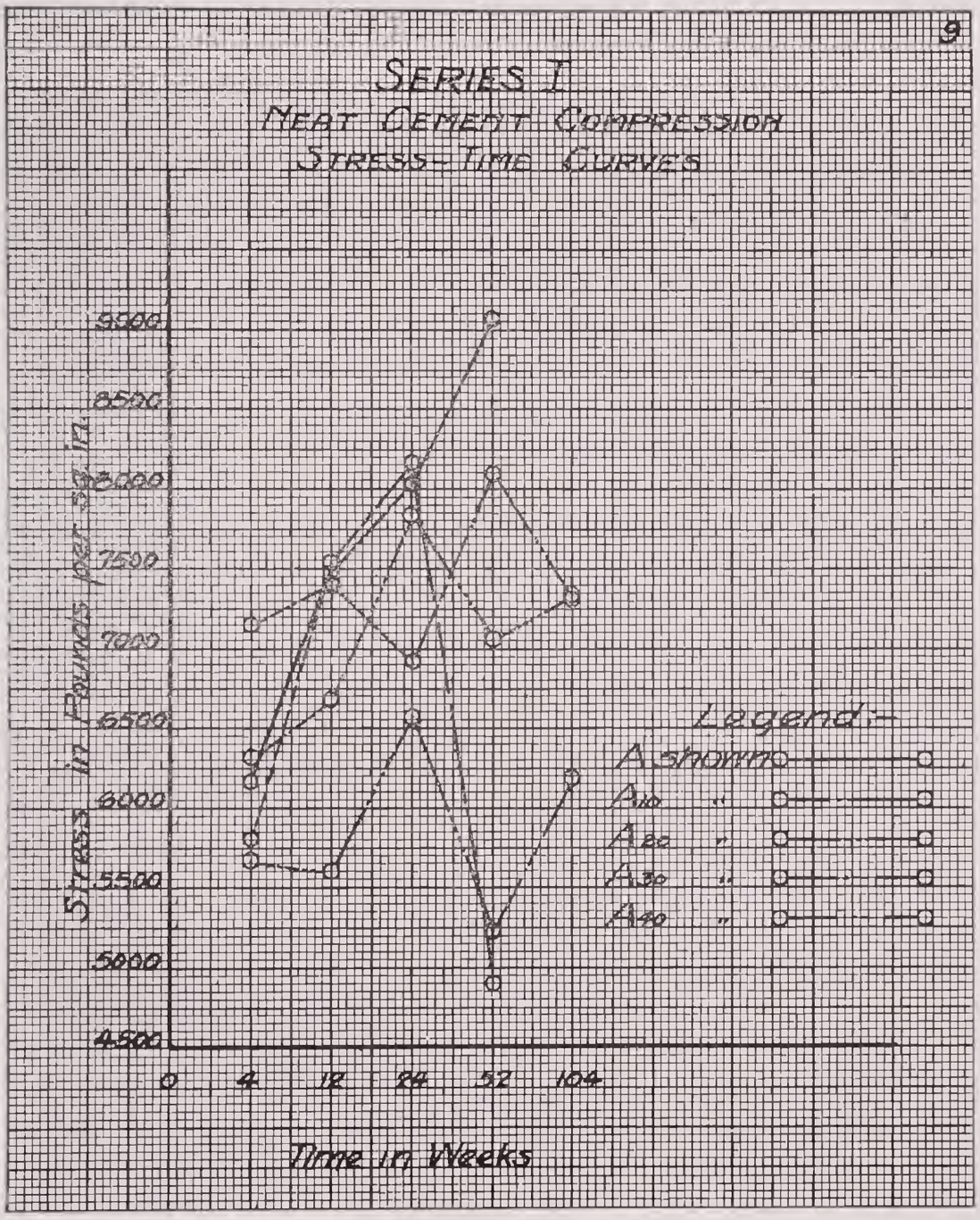

9
SERIES I
NEAT CEMENT COMPRESSION
STRESS-TIME CURVES
Stress in Pounds per Sq. In.
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
0
4
12
24
52
104
Time in Weeks
Legend:-
A shown
A10 "
A20 "
A30 "
A40 "

TABLE IX

Series I

RELATIVE STRENGTHS

Age of test in weeks	4	12	24	52
A	3	2	2	1
A_{10}	4	1	1	5
A_{20}	1	3	4	2
A_{30}	2	4	3	3
A_{40}	5	5	5	4

Up to the 52-week tests, A_{10} has developed the highest average relative strength; A, second; A_{20}, third; A_{30}, fourth; and A_{40}, fifth, although the first four classifications are not consistently defined. Inclusive of the 52-week tests the relative classification gives Cement "A" first rank; A_{20}, second; A_{10}, third; A_{30}, fourth; and A_{40}, fifth. No direct comparison can be made for the 104-week tests, as the "A" specimens were lost, but in view of the very great drop in the A_{10} specimens it appears that the final rank should be A, A_{20}, A_{30}, A_{40}, and A_{10} last.

Curve Sheet 10 is similar to Curve Sheet 9, except that the results plotted are for Lehigh Portland Cement "B" and blended cements of the same. (See Table C, Appendix A.) Here again many inconsistencies seem to exist; the tests of Cement "B" show marked variation in strength, it having attained a maximum strength at twelve weeks with an accompanying falling off of about 2500 pounds at the 24-week test-period. B_{10} develops an unusual strength at twelve weeks, but this is not maintained at the later period of testing. This cement develops a very satisfactory average strength throughout the period of testing. B_{20} develops very satisfactory strengths up to and including 24 weeks; but the 52-week test is unusually low. This 52-week test gave results, however, which are sufficiently uniform in range to warrant their acceptance and therefore no check tests were run. B_{30} is similar to B_{20}, the average results being somewhat higher. B_{40} seems to give the most consistent results of any of the cements in this series in point of range in strength developed, although its average strength is the lowest. The average strength of B_{40} is about 6400 pounds per square inch over the entire period of testing. Table X is similar to Table IX.

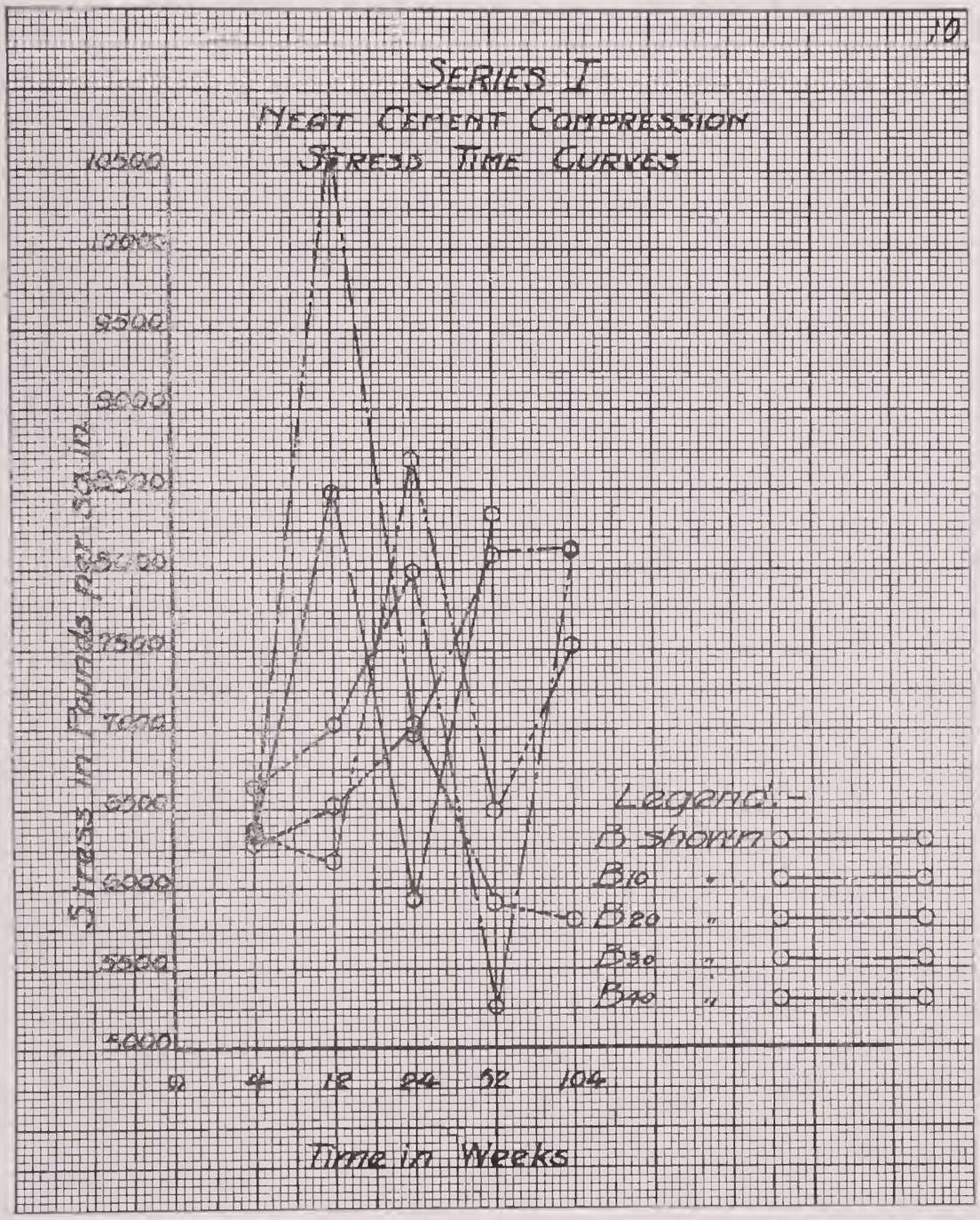

10
SERIES I
HEAT CEMENT COMPRESSION
STRESS TIME CURVES
10500
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
Stress in Pounds per Sq. In.
0
4
12
24
52
104
Time in Weeks
Legend:-
B shown
B10 "
B20 "
B30 "
B40 "

TABLE X

Series I

RELATIVE STRENGTHS

Age of test in weeks	4	12	24	52
B	3	2	5	1
B_{10}	2	1	3	2
B_{20}	1	3	2	5
B_{30}	3	5	1	3
B_{40}	5	4	4	4

In point of relative strength B_{10} seems to rank first. Since "B" and B_{20} have the same relative strengths during the entire period of testing, there is but little preference between them for second relative rank. B_{30} assumes fourth place, and B_{40}, fifth; this distinction, however, is not well defined; in point of excellence there seems to be but little real preference between cements B, B_{10}, B_{20}, and B_{30}. B_{40} is on the average probably somewhat inferior in strength to the others, but this inferiority is not pronounced.

The "B" specimens for 104 weeks were lost, and hence no comparison is made for this age.

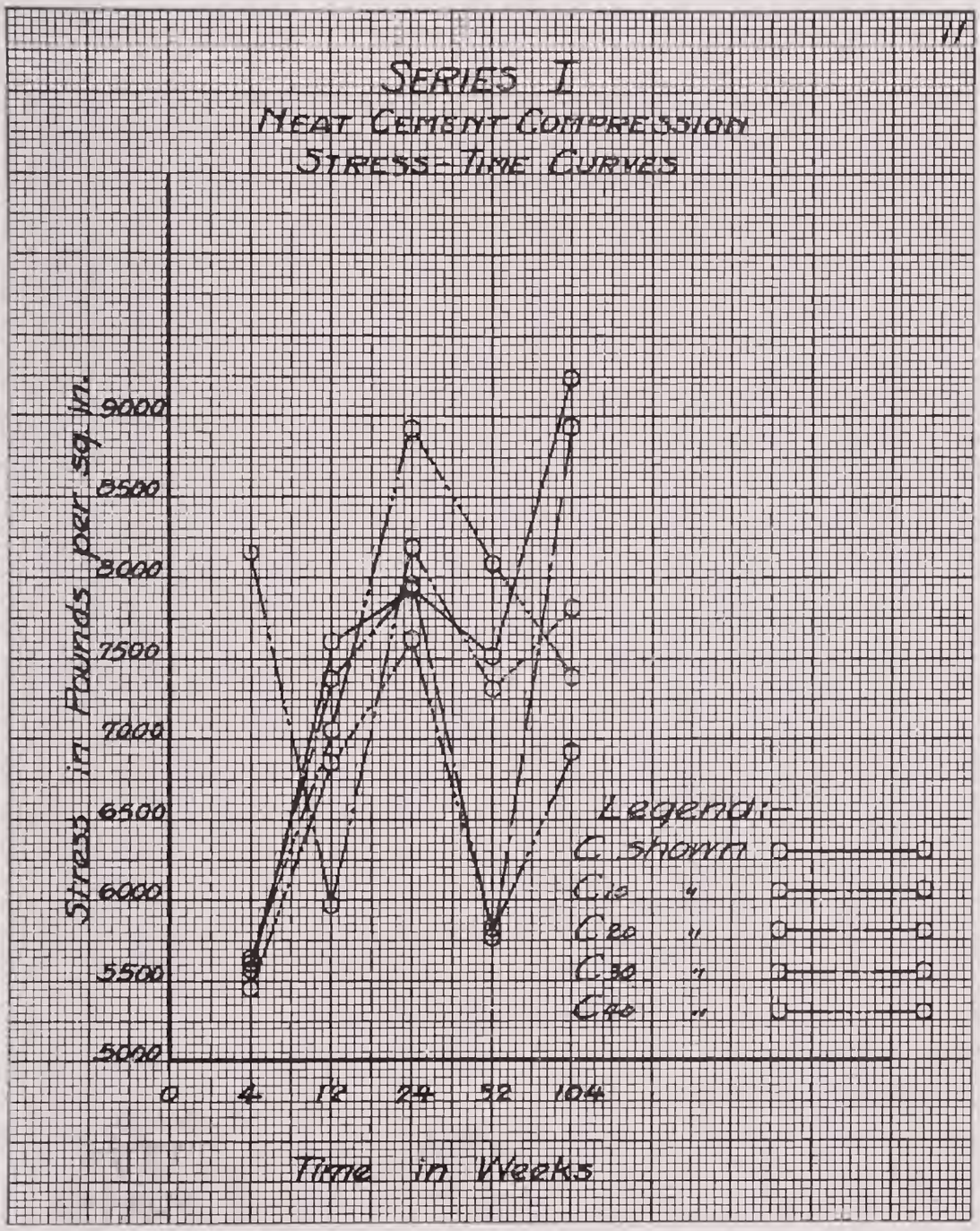
Curve Sheet 11 is similar to 9, differing only in the commercial cements used. The results here plotted are those obtained from tests of Red Ring Portland Cement "C" and blended cements of the same. (See Table C, Appendix A.) Were it not for the high strength attained at the 24-week period by Cement C_{20}, the curves here shown might seem to indicate that the various cements behave in a more or less uniform manner. The maximum strength in each case was developed at 24 weeks, with an accompanying falling off in strength at the test period of 52 weeks, increasing again for the 104-week tests.

TABLE XI

Series I

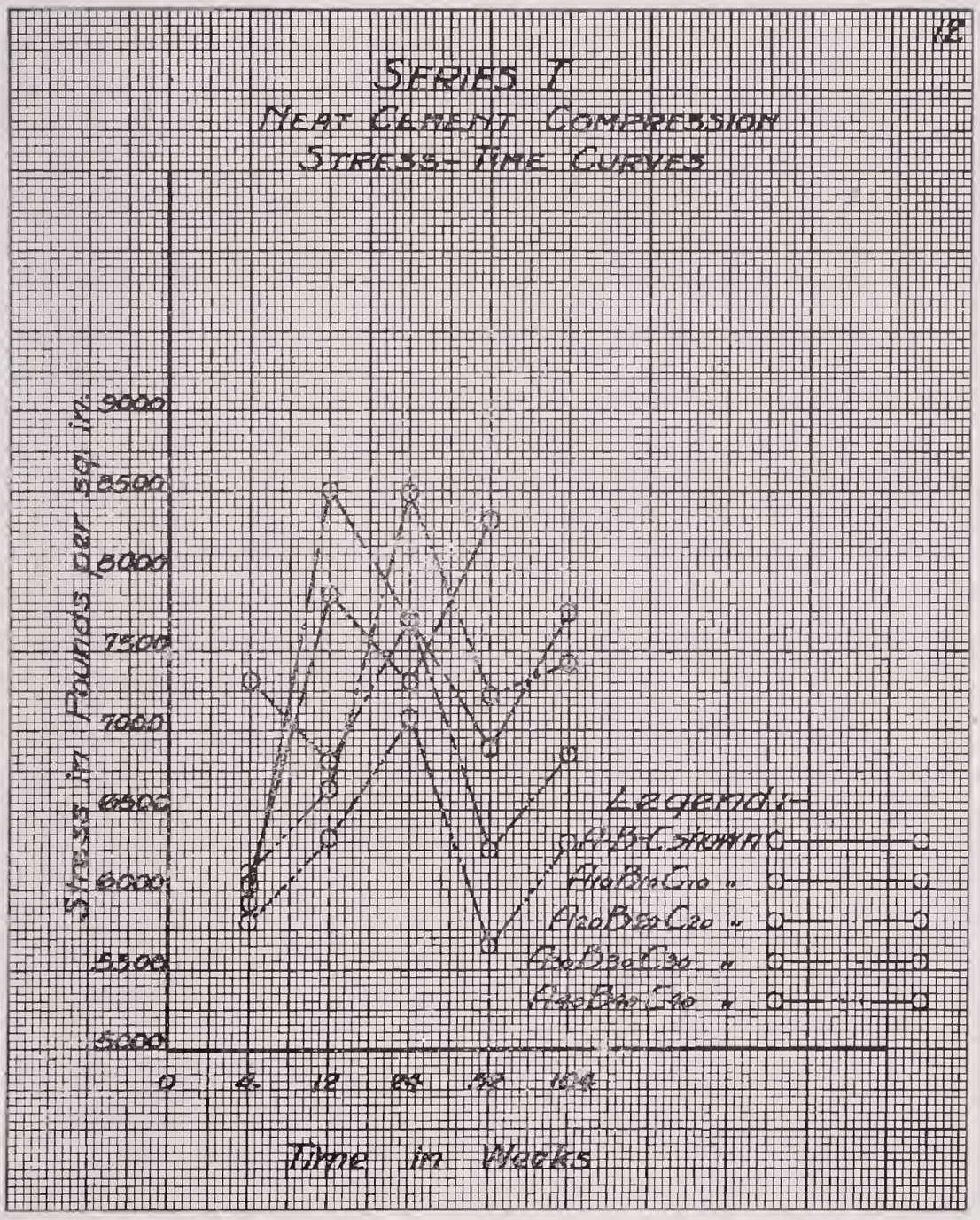
RELATIVE STRENGTHS

Age of test in weeks	4	12	24	52	104
C	4	1	3	2	1
C_{10}	2	2	4	4	2
C_{20}	1	5	2	3	3
C_{30}	3	3	1	1	4
C_{40}	5	4	5	5	5


SERIES I
NEAT CEMENT COMPRESSION
STRESS-TIME CURVES
Stress in Pounds per Sq. In.
9000
8500
8000
7500
7000
6500
6000
5500
5000
0
4
12
24
52
104
Time in Weeks
Legend:-
C shown
C 12 "
C 20 "
C 30 "
C 40 "

The above table, like the two previous ones, shows so much variation that it is problematical whether it has much real significance. From this table and in conjunction with Curve Sheet 11 the following relative classification is made: It is seen that cement C_{30} is far superior to the other tests at the 24 and 52-week peroids and is therefore given first relative rank. There is but little choice between C, C_{10}, and C_{20}, but should a distinction be made it is probable that "C" should receive second place, C_{20}, third; and C_{10}, fourth. C_{40}ranks fifth in relative importance.

Curve Sheet 12 is similar to Curve Sheet 8 in that the results plotted are the average of the three brands of commercial cement and the averages of the corresponding blended cements. (See Table C, "Average of averages," Appendix A.) This sheet shows the average results of neat cements in compression and is intended to represent such results as may be expected from an average Portland Cement and blended cements from the same. Here, as with the results which have been averaged, inconsistencies appear, but in less degree than these have been previously noted to occur. From averaging the results from testing commercial cements A, B, and C, it is seen that the strength increases satisfactorily up to the 24-week period, after which there is a falling off in strength. This is not excessive, however, and a complete recovery is noted at the 52-week test-period. In averaging the results of tests of A_{10}, B_{10}, C_{10}, an unusual increase is noted up to the 12-week period of testing. The succeeding tests, however, fall off very markedly, the strength at 52 weeks being considerably lower than that at 24. The averages obtained from A_{20}, B_{20}, and C_{20} show rather high strengths at four weeks. This characteristic has been noted in each of the separate 20 per cent blended cements. This high strength is not maintained at the twelve-week test-period, although the falling off is not excessive, the unit stress being about 500 pounds. A recovery is noted at 24 weeks with an accompanying falling off at the 52-week test-period. It may be said that the average strength throughout the entire period of testing of this average cement is quite satisfactory and uniform. The results obtained from averaging A_{30}, B_{30}, and C_{30} give a curve which is not unusual; there is a consistent increase in strength up to and including 24 weeks with a subsequent reduction in strength at 52 weeks. This reduction is not excessive and a further increase is noted at the age of two years. The average results of A_{40}, B_{40}, C_{40} give a curve which is quite similar to A_{30}, B_{30}, C_{30}, the results obtained


12.
SERIES I
NEAT CEMENT COMPRESSION
STRESS-TIME CURVES
Stress in Pounds per sq. in.
9000
8500
8000
7500
7000
6500
6000
5500
5000
0
4
12
26
52
104
Time in Weeks
Legend:-
A2B2C1 from O
A1a B1a C1a "
A2a B2a C2a "
C1a B3a C3a "
A2a B1a C2a "

at any period of testing, however, being somewhat lower. The relative comparison of strengths is interesting. This is afforded by a study of Table XII, which is similar to the tables of relative strength previously alluded to.

TABLE XII

Series I

RELATIVE STRENGTHS

Age of test in weeks	4	12	24	52
A B C	3	2	4	1
A_{10} B_{10} C_{10}	4	1	2	4
A_{20} B_{20} C_{20}	1	3	2	3
A_{30} B_{30} C_{30}	2	4	1	2
A_{40} B_{40} C_{40}	5	5	5	5

By reference to the above table and Curve Sheet 12, the following relative comparison is made. In reverse order it is noted that the average of cements A_{40}, B_{40}, C_{40} is consistently lowest in strength and therefore is classified fifth. Due to the falling off in strength at the 24- and 52-week periods, the average of cements A_{10}, B_{10}, C_{10} is given fourth rank in relative importance. Of the three remaining averages, there is scarcely sufficient variation in strengths to warrant relative differentiation. The averages of the 30 percent blended cements show a slight increase over the 20 per cent averages, the falling off in strength at the 12-week period is against the later, and the greater strength developed in the former at the later periods may warrant the average of A_{30}, B_{30}, C_{30} being classified ahead of the average of A_{20}, B_{20}, C_{20}. No effort is made to differentiate between the average results of A, B, C, and A_{30}, B_{30}, C_{30}.

It should be noted throughout these tests in compression that while irregularities occur they are not confined to the blended cements. The Portland Cements manifest eccentricities difficult to explain. The results were not all that was expected, but if they have been interpreted aright they indicate that the blended cements compare favorably with the Portland Cements in tests for neat compression.

(D) Cement Mortar in Compression.

The American Society for Testing Materials, in the revision of standard specifications and tests for Portland Cement, proposed the addition of a test which has not hitherto been required, namely, a test for compressive strength of Portland Cement mortar. (See proceedings of the American Society for Testing Materials Vol. 16, page 590.) It is proposed that the average strength in pounds per square inch of not less than three standard test pieces composed of one part of cement and three parts of sand, by weight, shall be equal to or greater than 1200 pounds per square inch at the age of seven days and 2000 pounds per square inch at the age of 28 days, the specimens having been stored one day in moist air the remaining time in water. It is proposed that the test pieces be cylinders 2 inches in diameter and 4 inches high. The results herein reported differ from the above suggestions only in the method of manufacture and in the height of cylinders. The specimens used were 2 inches high instead of 4 inches, as recommended. It should be noted that these specimens were prepared before the appearance of the tentative revisions of the American Society for Testing Materials. No tests were made at seven days.

On Curve Sheet 13 are plotted the results obtained from testing mortar specimens of Atlas Portland Cement "A" and blended cements of the same. (See Table D Appendix A.) The strengths obtained increased consistently during the first 12 weeks and with but one exception, (A_{40}), attained strengths greater than 2000 pounds per square inch at 28 days (the proposed requirements as noted above). With the exception of A_{10} all cements attain their maximum strength at 12 weeks, A_{10} attaining it at 24 weeks. A relative comparison in strength is afforded by Table XIII, which is similar to the previous tables.

TABLE XIII

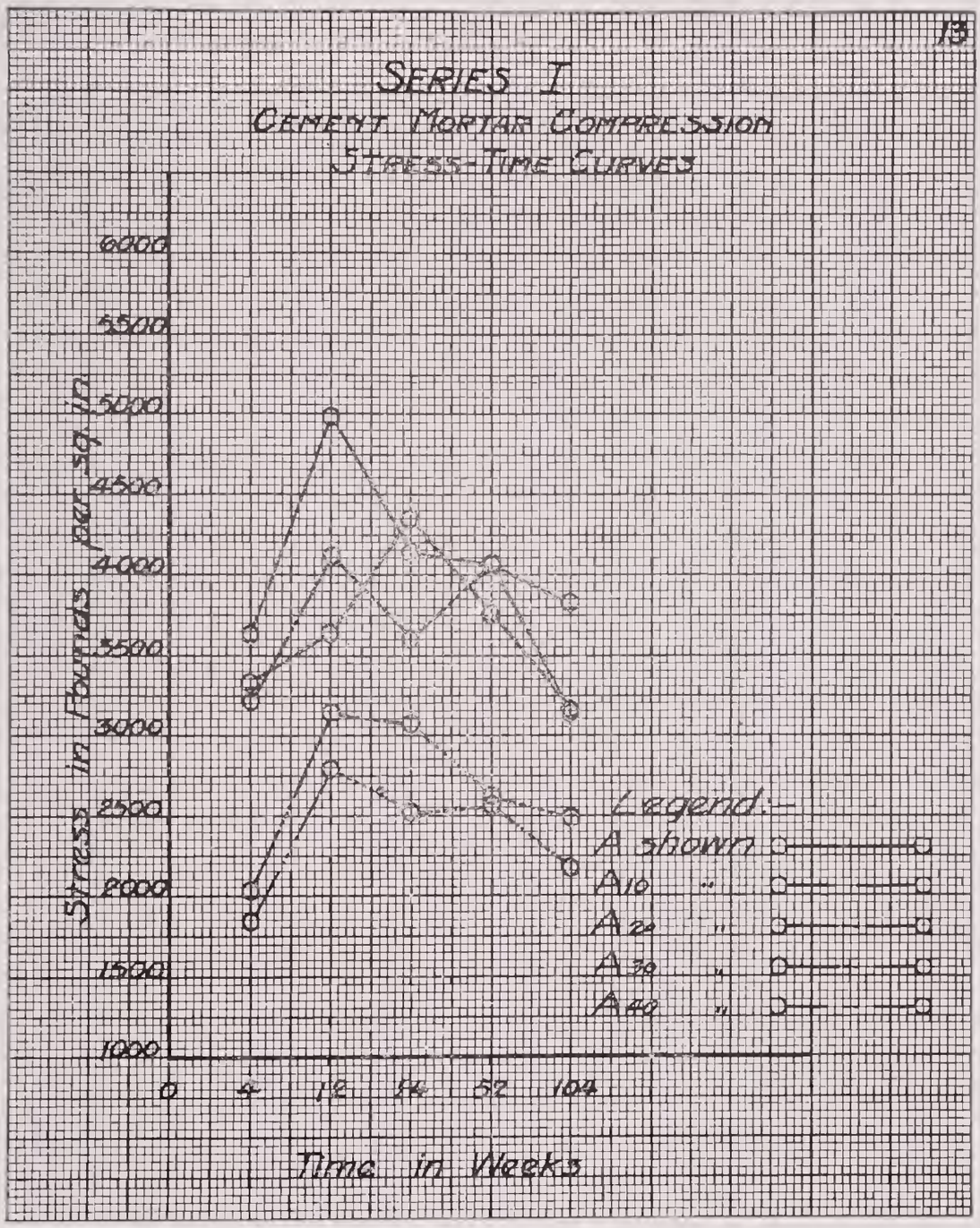
Series I

RELATIVE STRENGTHS

Age of test in weeks	4	8	12	24	52	104
A	1	1	2	1	1	1
A_{10}	2	3	1	3	3	2
A_{20}	3	2	3	1	2	3
A_{30}	4	4	4	4	4	4
A_{40}	5	5	5	5	5	5

Cement "A" seems to have attained the highest relative strength throughout the period of testing although after the 12 weeks tests this classification is not so pronounced. There is but little choice between A_{10} and A_{20} and these are easily superior to A_{30} and A_{40}, the latter receiving fourth and fifth places respectively in relative strengths.

A noticeable fact, which is not explained, is that each cement shows a decrease in strength from the 52-week to the 104-week test, all in about the same ratio.


13
SERIES I
CEMENT MORTAR COMPRESSION
STRESS-TIME CURVES
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
Stress in Pounds per sq. in.
0
4
12
24
52
104
Time in Weeks
Legend:-
A shown
A10 "
A24 "
A30 "
A40 "

Curve Sheet 14 is similar to Curve Sheet 13, the results plotted being attained from compressive tests of mortar specimens of Lehigh Portland Cement "B" and blended cements of the same. (See Table D, Appendix A.) The results shown, with the exception of Cement B_{40} satisfy the proposed requirements, as has been previously noted, of the American Society for Testing Materials at 28 days. There is not quite the same consistency in results here as is shown on Curve Sheet 13. Cement "B" shows a loss in strength at 12 weeks. This loss is not excessive and is overcome as shown in the 24- and 52-week tests. Cement B_{10} shows rather more uniform results than does A_{10} and the strengths attained average somewhat higher. The curve B_{20} attains the highest strength at 12 weeks with an accompanying falling off at 24. The maximum strength, however. is attained at 52 weeks. The average strength of this cement throughout the entire period of testing is quite high, being about 3100 pounds per square inch. A consistent increase in strength is shown in the results of B_{30}, up to 24 weeks when the maximum strength is attained. The loss at 52 weeks, however, is not excessive nor unusual. Cement B_{40} shows rather lower strengths at all periods of testing than do the other cements, the curve is quite uniform, however, and is probably quite representative of cement mortars having such high percentage of blending material in the cement. Table XIV is similar to Table XIII.

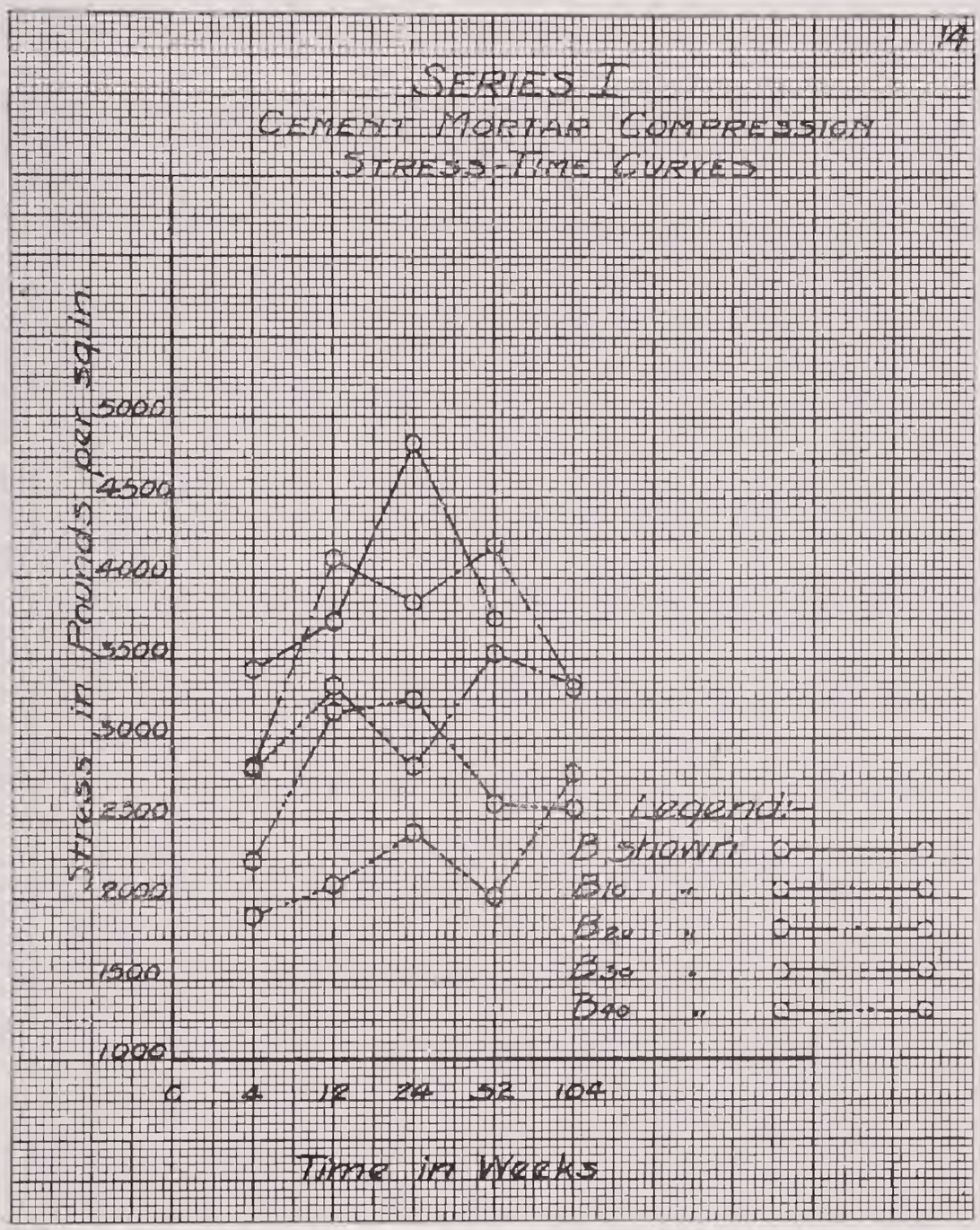
TABLE XIV

Series I

RELATIVE STRENGTHS

Age of test in weeks	4	12	24	52
B	1	2	1	2
B_{10}	2	1	1	1
B_{20}	3	3	4	3
B_{30}	4	4	3	4
B_{40}	5	5	5	5

A study of the above table in conjunction with Curve Sheet 14 shows but little choice between Cements "B" and B_{10}, but a slight preference at the early periods of testing for the former seems to be warranted. At the later periods, however, the preference is reversed. In consequence, the following classification is given: Cement B_{10}


14
SERIES I
CEMENT MORTAR COMPRESSION
STRESS-TIME CURVES
Stress in Pounds per Sq. In.
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
4
12
24
32
104
Time in Weeks
Legend:-
B shown
B10
B20
B30
B40

ranks first; "B", second; B_{20}, third; B_{30}, fourth; and B_{40}, fifth. As the "B" specimens for 104 weeks were lost, no comparison is made at this age.

Curve Sheet 15 shows the plotted results of mortar compression tests of Red Ring Portland Cement "C" and the blended cements of the same. (See Table D, Appendix A.)

A wide range in the results obtained in this series of tests characterizes this curve sheet. The values obtained by Cement "C" are uniformly high; those by C_{40} are low; the difference in strength averages about 2300 pounds per square inch throughout the entire period of testing. It is felt that this range is probably excessive. Separately, the curves may be considered quite satisfactory. Curve "C" attains maximum strength at twelve weeks with a reduction at 24 weeks, followed by a gain at 52 weeks and a further gain at 104 weeks. Curve C_{10} consistently increases in strength to a maximum at 24 weeks with a slight reduction in strength at 52 weeks and at 104 weeks. Curve C_{20} is similar to Curve "C" in outline; the strengths developed in the former range about two-thirds of those of the latter. The results of testing C_{30} give a curve which is in no sense unusual, a consistent increase in strength being noted up to twenty-four weeks with a slight falling off in the 52-week test. Curve C_{40} is consistently lower in strengths than the other curves. Table XV is similar to the previous tables of relative strengths.

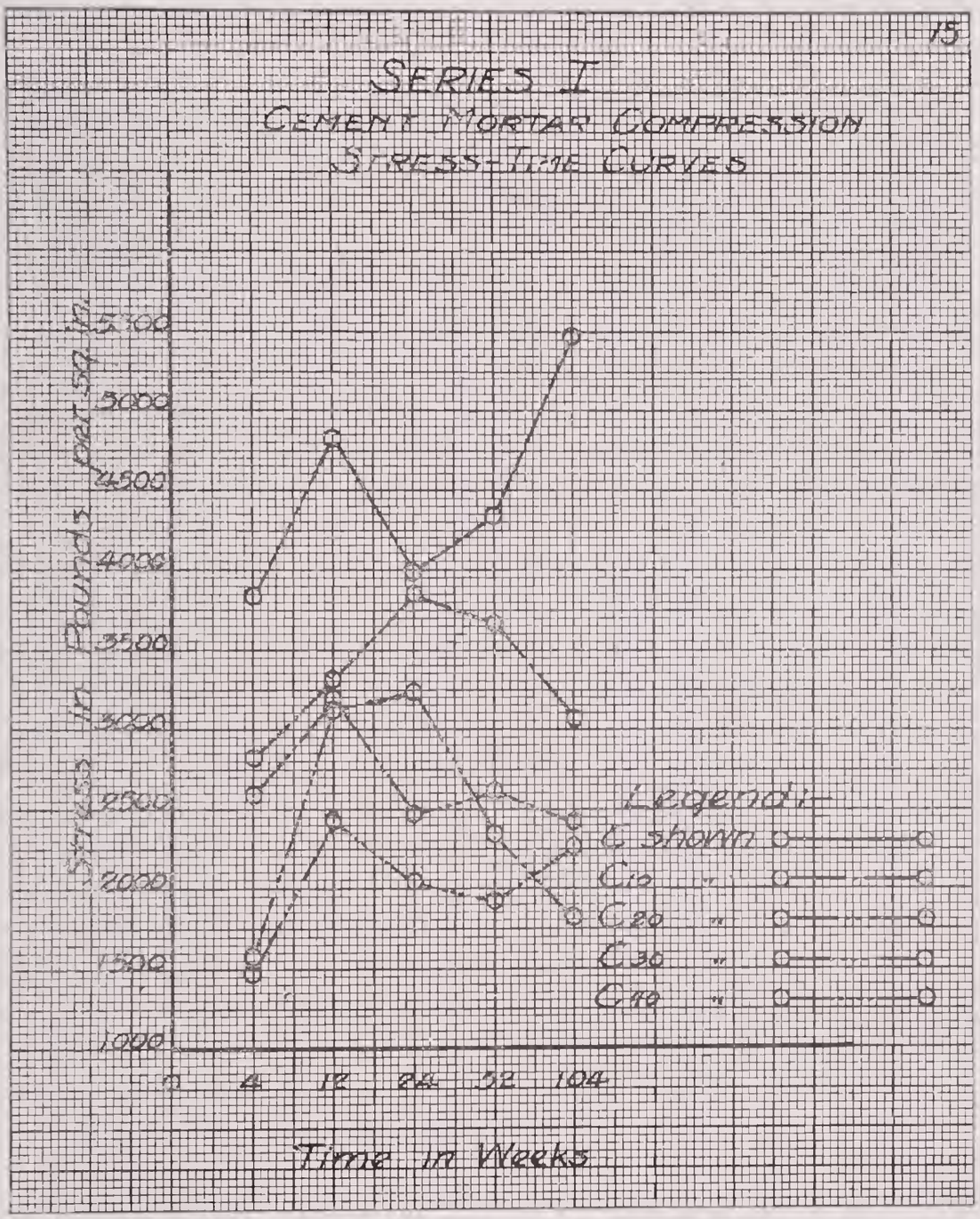
TABLE XV

Series I

RELATIVE STRENGTHS

Age of test in weeks	4	12	24	52	104
C	1	1	1	1	1
C_{10}	2	2	2	2	2
C_{20}	3	3	4	3	3
C_{30}	4	4	3	4	5
C_{40}	5	5	5	5	4

The above table shows an easy comparison of relative strengths, the strengths decreasing as the blending material increases. The mortar from the commercial Portland Cement ranks higher in strength throughout the entire peroid of testing.

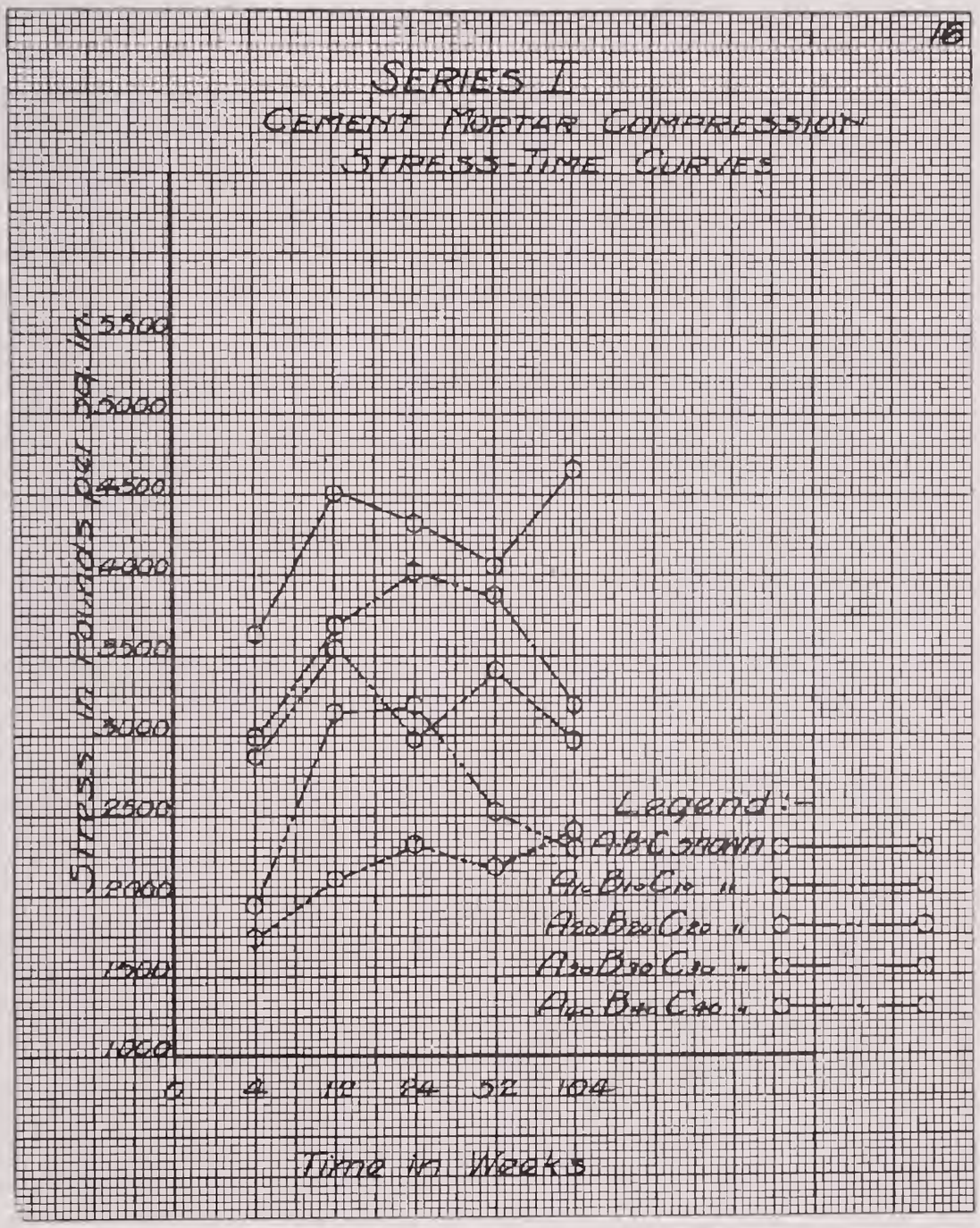

15
SERIES I
CEMENT MORTAR COMPRESSION
STRESS-TIME CURVES
Pounds per Sq. In.
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
4
12
24
32
104
Time in Weeks
Legend:
C shows
C10 "
C20 "
C30 "
C40 "

The results obtained from averaging the corresponding tests of the three previous curve sheets are plotted on Curve Sheet 16. (See Table D, "Average of averages," Appendix A.)

It will be noted that the results of tests of mortar specimens from the 40 per cent blended cements are relatively low, falling below the requirements of the proposed specifications of the American Society for Testing Material. Results from the tests of the 30 per cent blended cements reveal higher strengths than those of the 40 per cent but in this case the requirements of the proposed specifications of the American Society for Testing Material are not satisfied, the strengths being about 60 pounds per square inch less than the requirements at 28 days. The results from the 10 and 20 per cent blended cement mortars are well within the specifications referred to and are quite satisfactory in strength throughout the entire period of testing. A relative comparison is made from Curve Sheet 16. Here is it easily seen that the strengths developed throughout the entire period of testing vary inversely with the amount of blending material used, in an almost direct ratio.

(E) Normal Consistency.

The amount of water required to bring the various cement pastes to normal consistency is plotted on Curve Sheet 17. (See Table XVI). As would be expected, the amount of water increases rapidly from that required for Portland Cement to that required for the 10 per cent blended cement. For, as has been previously stated, the latter carries a higher percentage of the extremely fine Portland Cement than does the former, and in consequence should demand more water if the same degree of hydration is to take place. As the percentage of the blending material increases, the amount of water required should decrease and this assumption is clearly shown to be correct by the accompanying curve sheet.


16
SERIES I
CEMENT MORTAR COMPRESSION
STRESS-TIME CURVES
Stress in Pounds per Sq. In.
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
4
12
24
52
104
Time in Weeks
Legend:-
A.B.C. shown
A1 B1 C1 0 "
A2 B2 C2 0 "
A3 B3 C3 0 "
A4 B4 C4 0 "

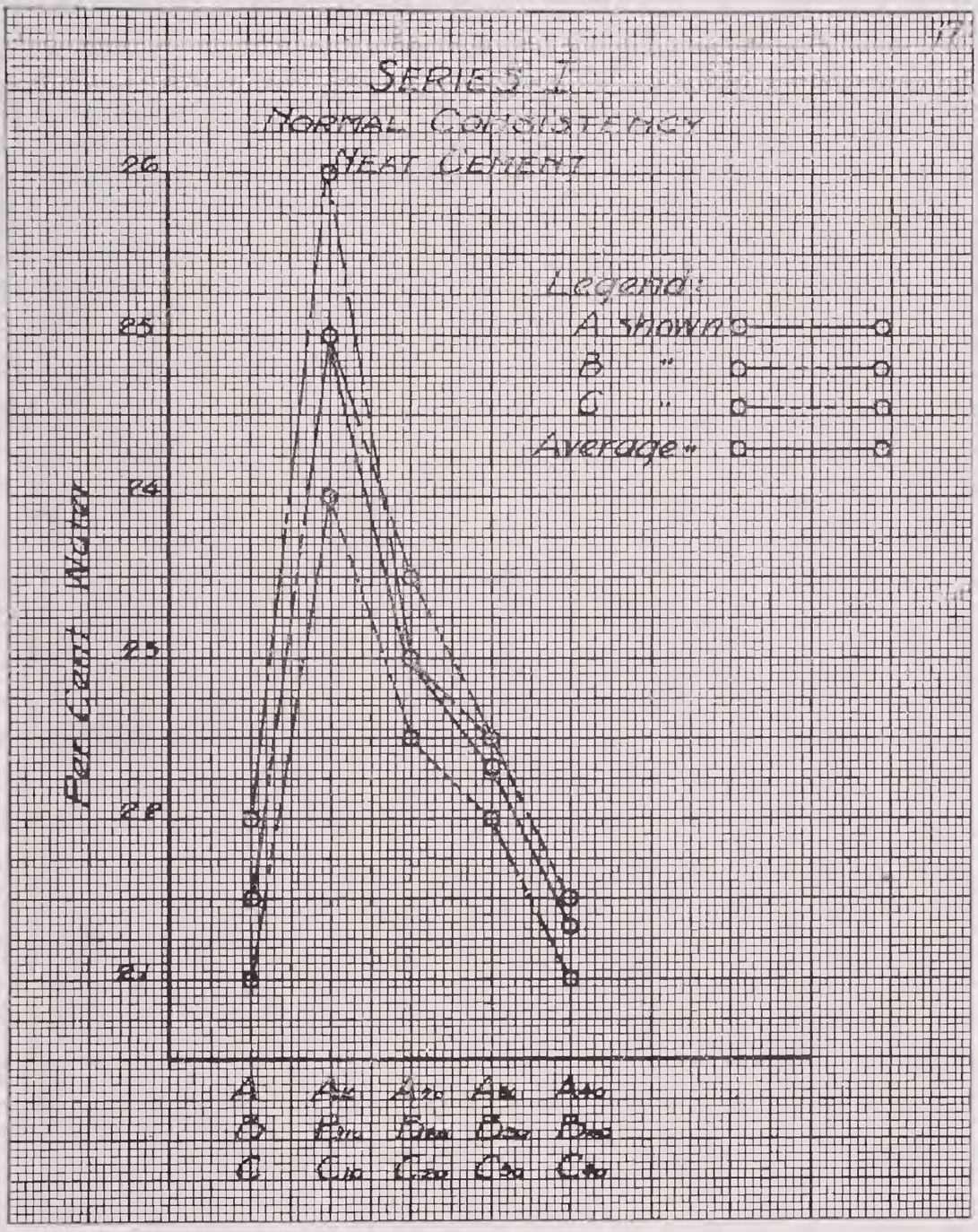
It was assumed in preparing the blended cements that about 30 per cent of the Portland Cement was removed, that which was retained on a No. 200 sieve being at least that amount. The sifting was not continued to the extent that would be required in a test for fineness. It is not unusual, then, that the 30 per cent blended cement requires approximately the same amount of water for normal consistency as the Portland Cement. As the percentage of water required for normal consistency for mortar specimens was obtained from the standard conversion tables of the specifications of the United States Government for Portland Cement mortar, the characteristics noted above apply to mortar as well as to cement paste.

TABLE XVI

Series I

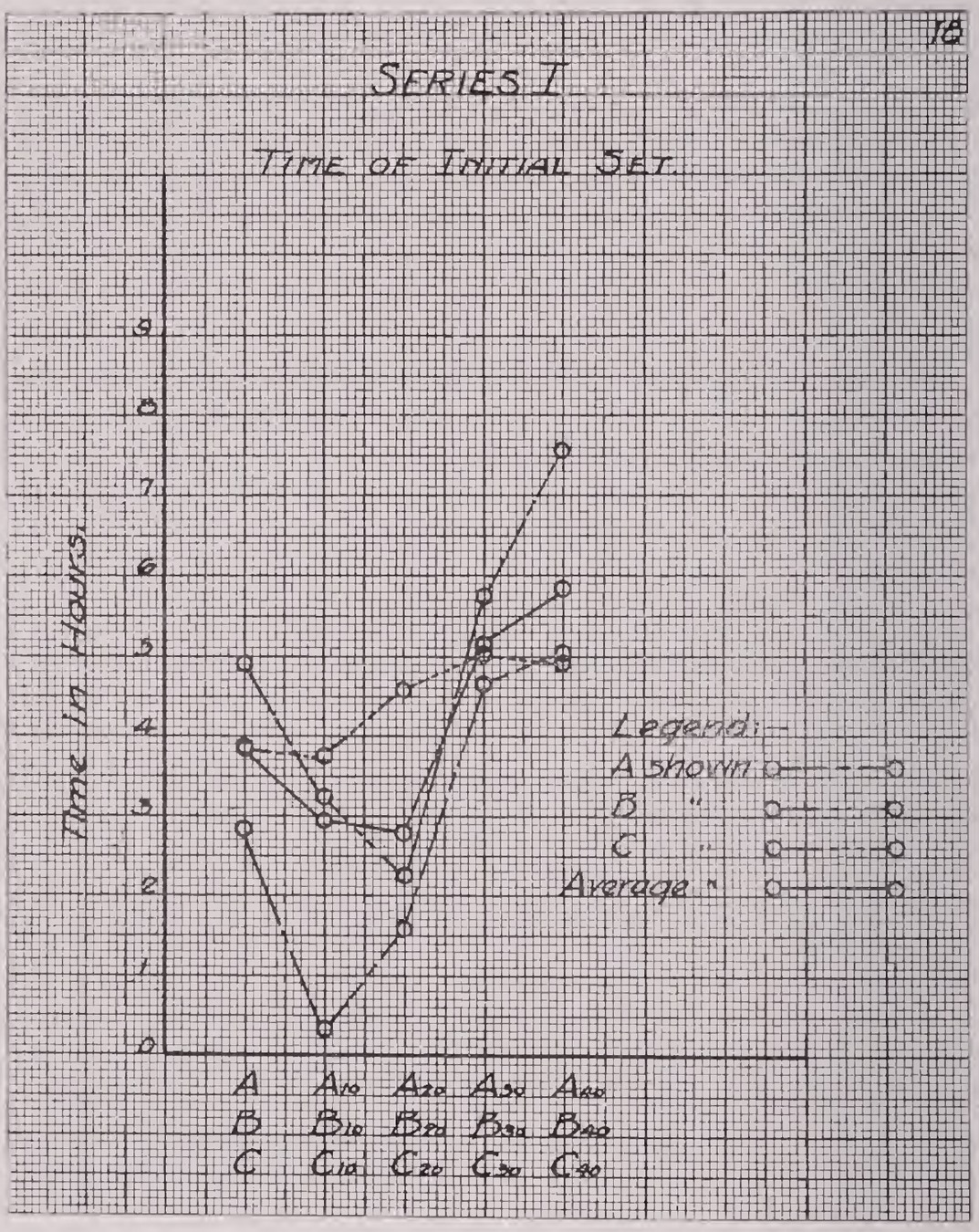
TIME OF SET AND NORMAL CONSISTENCY

	Time of Set By Vicat				Normal Consistency	
	Initial		Final			
	Hours	Minutes	Hours	Minutes	Neat Paste Per Cent	1:3 Sand Mortar Per Cent
A	2	50	5	20	22	10.2
A_{10}	0	20	5	10	26	10.8
A_{20}	1	35	5	30	23	10.3
A_{30}	4	40	8	30	22½	10.25
A_{40}	5	03	6	23	21½	10.1
B	4	55	9	00	21	10.1
B_{10}	3	15	6	20	24	10.5
B_{20}	2	15	5	50	22½	10.25
B_{30}	5	45	9	35	22	10.2
B_{40}	7	35	10	15	21	9.9
C	3	50	5	55	21½	10.1
C_{10}	3	45	6	—	25	10.7
C_{20}	4	35	8	10	23½	10.4
C_{30}	5	02	7	25	22½	10.25
C_{40}	4	55	7	25	21½	10.1
Averages						
A, B, C	3	52	6	45	21½	10.13
A_{10} B_{10} C_{10}	2	27	5	50	25	10.66
A_{20} B_{20} C_{20}	2	48	6	30	23	10.32
A_{30} B_{30} C_{30}	5	09	8	30	$22^1/_3$	10.23
A_{40} B_{40} C_{40}	5	51	8	01	$21^1/_3$	10.03

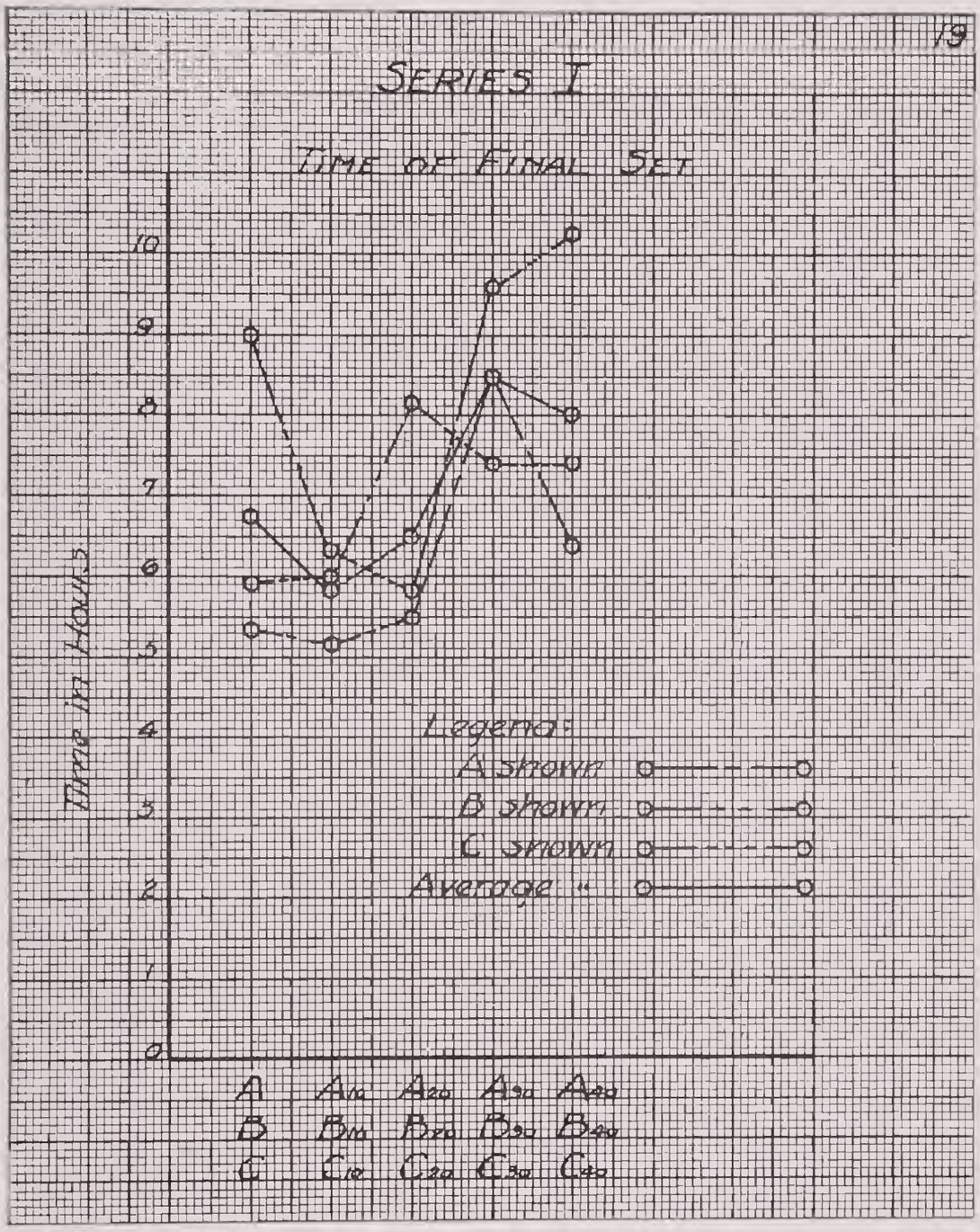

SERIES I.
NORMAL CONSISTENCY
NEAT CEMENT
Legend:
A shown
B "
C "
Average "
Per Cent Water
26
25
24
23
22
21
A
B
C

(F) Time of Setting.

The time required to produce initial and final setting was determined with the Vicat apparatus, and is shown plotted on Curve Sheets 18 and 19, respectively. It is tabulated in Table XVI. It is significant that the time of setting is less in the case of the 10 per cent blended cements



than with the Portland Cements. As the percentage of blending material increases, the time of setting increases until, when a blending material of between 20 and 30 per cent has been used, the time of setting of the blended ce-


19
SERIES I
TIME OF FINAL SET
Time in Hours
10
9
8
7
6
5
4
3
2
1
0
Legend:
A shown
B shown
C shown
Average "
A A10 A20 A30 A40
B B10 B20 B30 B40
C C10 C20 C30 C40

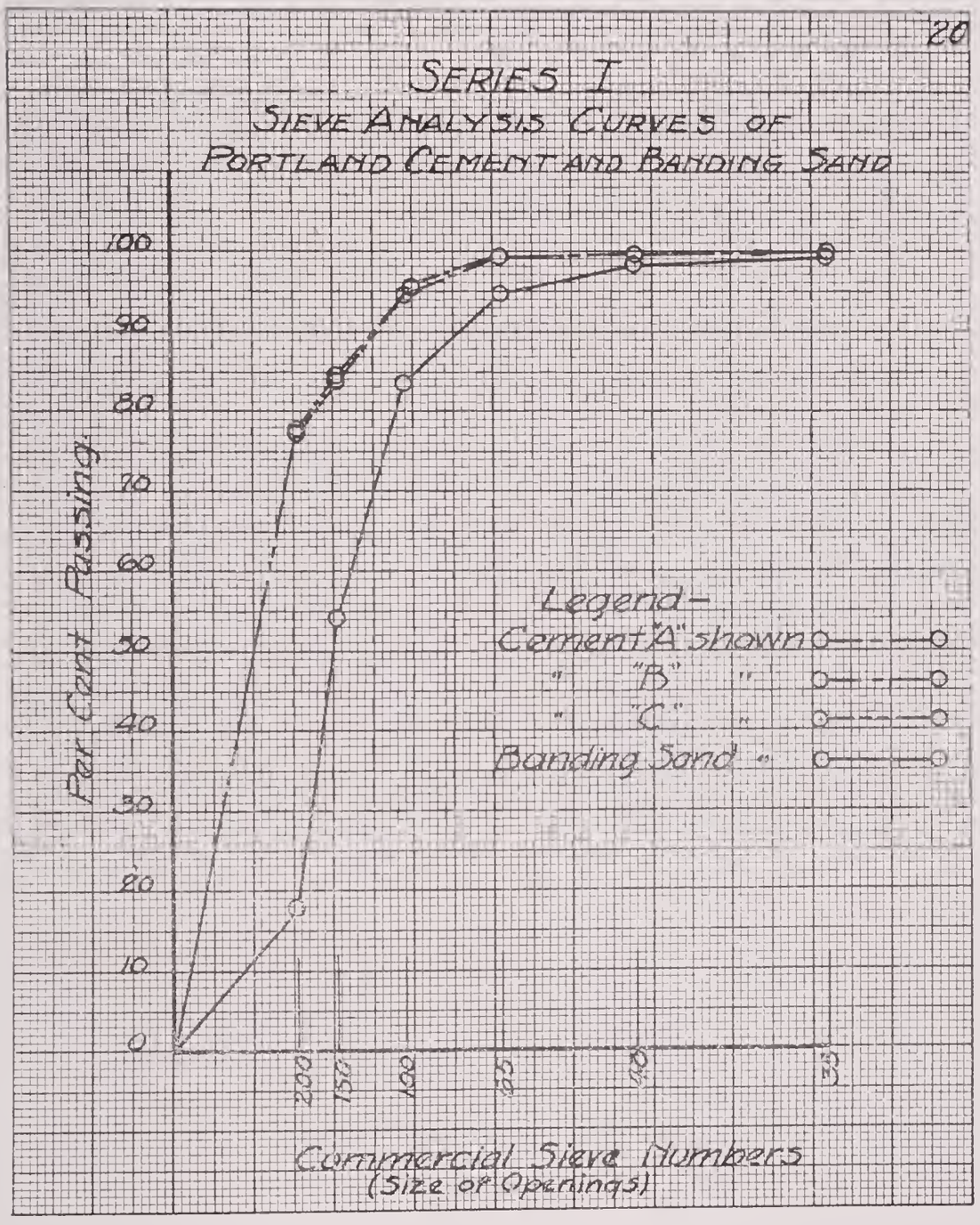
ment is equal to that of the Portland Cement. The 40 per cent blended cements are somewhat slower in setting than the Portland Cements.

(G) Constancy of Volume.

The usual tests, normal and accelerated, for the determinations of soundness were made. The standard methods suggested by the American Society of Civil Engineers were followed in these tests. The specimens were observed for periods of one year and in every instance the standard specifications were fulfilled. Each of the specimens remained true and sound throughout this entire period.

(H) Fineness and Sieve Analysis.

The curves of sieve analysis shown on Curve Sheet 20 were plotted from the data compiled in Table XVII. It will be noted that the fineness of these Portland Cements easily satisfied the specifications of the American Society for Testing Materials and that there was but little difference in the gradation of the size of particles, cements A and B having almost identical curves of sieve analysis. The banding sand is shown to be well graded between the No. 65 and No. 200 sieves, this portion of the curve comparing favorably with the same portion of the Portland Cement curves. By combining this cement and sand, as has been previously indicated, that is, by using only that portion of the cement passing the No. 200 sieve and that portion of the sand passing the No. 65 sieve, a combined curve can be obtained which is quite similar to the Portland Cement curves. Curve Sheet 21 has been prepared showing the gradation of the Portland Cement after the removal of the coarse particles (those retained upon a No. 200 sieve) and of the banding sand after the removal of particles larger than the No. 65 sieve openings. The combinations of these are shown as combined curves and are typical of the gradation of the blended cements. It will be noted here that the blended cement containing 30 percent of sand has a gradation in size of particles almost identical with that of the


SERIES I
SIEVE ANALYSIS CURVES OF
PORTLAND CEMENT AND BANDING SAND
Per Cent Passing
100
90
80
70
60
50
40
30
20
10
0
Legend—
Cement "A" shown
" "B" "
" "C" "
Banding Sand "
20
50
80
100
Commercial Sieve Numbers
(Size of Openings)

Portland Cements. The data plotted on Curve Sheet 21 were computed but it is thought that they should reasonably approximate experimentally derived data.

TABLE XVII

Series 1

SIEVE ANALYSIS

Cement Series No.	Percentages						
	Passing No. 200	Retained on No. 200	Retained on No. 150	Retained on No. 100	Retained on No. 65	Retained on No. 48	Retained on No. 35
A	78.0	22.0	15.3	5.6	0.7	0.1	0.0
B	78.2	21.8	15.9	6.1	0.75	0.0	0.0
C	77.3	22.7	16.4	4.6	0.8	0.3	0.1
Sand	17.9	82.1	55.9	16.4	5.1	1.8	0.6

(I) Chemical Analysis and Specific Gravity.

The chemical analyses recorded in Table XVIII are partly laboratory determinations and partly determinations arrived at by computation. The three commercial Portland Cements and the Banding Sand were analyzed by Mr. R. P. Rinker, Chemist for the Missouri Bureau of Geology and Mines, through the courtesy of Mr. H. A. Buehler, Director. Analyses were furnished by the various cement companies. The results obtained by Mr. Rinker and those furnished by the Cement companies are so nearly identical that only those of the former are shown. The analyses of the various blended cements are the results of combining the analysis of the banding sand with the analysis of the Portland Cement blended in the ratio of the combination, sand to cement.

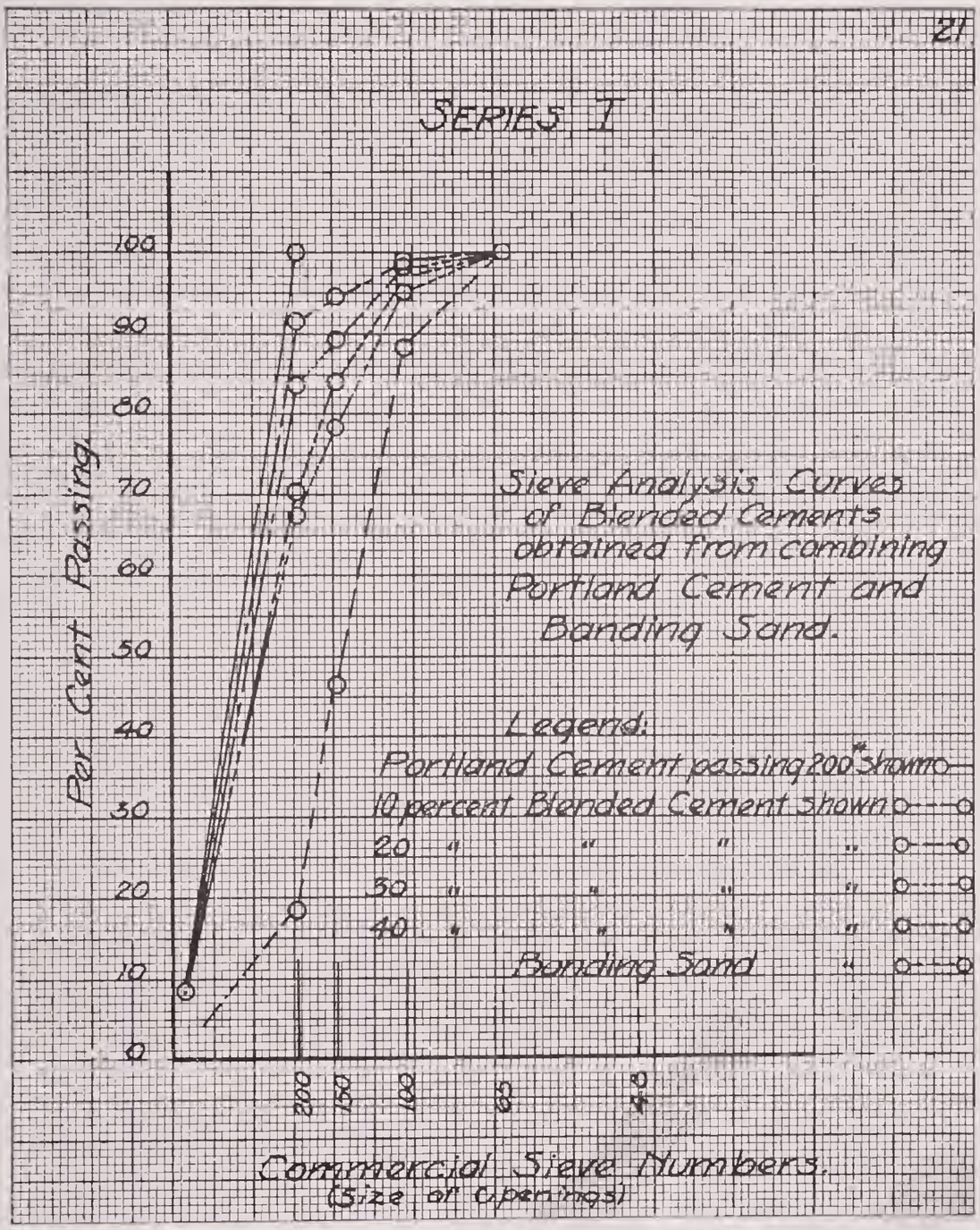

21
SERIES I
Per Cent Passing
100
90
80
70
60
50
40
30
20
10
0
Sieve Analysis Curves of Blended Cements obtained from combining Portland Cement and Banding Sand.
Legend.
Portland Cement passing 200 shown
10 percent Blended Cement shown
20 " " " "
30 " " " "
40 " " " "
Banding Sand " "
200
150
100
65
48
Commercial Sieve Numbers.
(Size of Openings)

TABLE XVIII

Series I

CHEMICAL ANALYSIS AND SPECIFIC GRAVITY

Analysis of Cements

Cement Serial Number	Ignition Loss	Percentage of							Sp. Gr.	
		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Total	Computed	Determined
A	1.80	21.48	2.57	5.89	63.32	3.00	1.50	100.06		3.184‡
A_{10}	1.65	29.64	2.28	5.30	56.97	2.70	1.30	99.90	3.135	*
A_{20}	1.50	37.31	2.02	4.86	50.66	2.40	1.20	99.95	3.084	*
A_{30}	1.35	44.88	1.89	4.33	44.33	2.10	1.05	99.93	3.033	*
A_{40}	1.21	52.65	1.66	3.81	38.01	1.80	0.90	100.04	2.984	*
B	1.80	21.46	2.85	6.81	63.56	2.10	1.46	100.04		3.176‡
B_{10}	1.65	29.18	2.59	6.20	57.21	1.89	1.31	100.03	3.126	*
B_{20}	1.50	36.90	2.31	5.58	50.85	1.68	1.17	99.99	3.076	*
B_{30}	1.35	44.62	2.09	4.97	44.49	1.47	1.02	100.01	3.028	*
B_{40}	1.21	52.32	1.83	4.36	38.14	1.26	0.87	99.99	2.977	*
C	0.60	22.70	3.07	7.55	63.58	1.22	1.53	99.85		3.208‡
C_{10}	0.57	30.08	2.79	6.87	56.80	1.09	1.37	99.57	3.155	*
C_{20}	0.54	37.88	2.51	6.18	50.61	0.97	1.22	99.91	3.102	*
C_{30}	0.52	45.49	2.24	5.49	44.21	0.85	1.07	99.87	3.049	*
C_{40}	0.49	53.08	1.96	4.81	37.91	0.73	0.91	99.89	2.996	*
Banding Sand	0.32	98.66	0.31	0.69	0.04			100.02		2.681‡

‡Laboratory Analysis. *Computed Analysis.

SUMMARY

In summarizing the foregoing, the following observations have been noted:

(A) Neat Cement in Tension.

Portland Cement and blended cements gain in strength at approximately the same rate.

Portland Cement develops slightly greater strength at early periods of testing than does a blended cement.

At 24 weeks and later the 30 and 40 per cent blended cements are equal in strength to the Portland Cement, the 10 and 20 per cent blended cements showing to slightly less advantage.

(B) Cement Mortar In Tension.

The rate of gain in strength in Portland Cement mortar and blended cement mortar is approximately the same.

Within the scope of this investigation Portland Cement mortar is not superior in strength to blended cement mortar.

When the amount of blending material used does not exceed 30 per cent, blended cement mortar develops greater strength than does Portland Cement mortar.

(C) Neat Cement In Compression

The results obtained are unsatisfactory, owing to lack of uniformity.

When the amount of blending material used does not exceed 30 per cent, the relative strength of the blended cements compares favorably with that of commercial Portland Cement.

(D) Cement Mortar In Compression.

Within the scope of these tests Portland Cement mortar develops greater strength than does blended cement mortar.

The strength of mortar varies inversely with the amount of blending material used.

When the amount of blending material does not exceed about 30 per cent such blended cement mortar may be expected to pass satisfactorily the proposed specifications of the American Society for Testing Materials.

Note:—It seems unusual that the results obtained from testing cement mortars in tension are so contradictory to those obtained from testing similar cement mortars in compression; the former favoring the blended cements, while the latter show the Portland Cement to be superior in strength.

(E) Normal Consistency.

Within the scope of this investgation, Portland Cements differ in normal consistency within narrow lmits.

The normal consistency of blended cements varies inversely with the amount of the blending material used.

(F) Time of Setting.

Within the scope of this investigation, Portland Cements differ in time of setting within wide limits.

Blended cements, having more than 20 per cent of blending material, seem to develop initial and final setting more slowly than do the Portland Cements of which they are composed.

Blended cements, having not to exceed 40 per cent of blending material, satisfy the requirements of the present standard specifications for the time of setting of Portland Cements.

(G) Constancy of Volume.

Blended cements ,having not to exceed 40 per cent of blending material, satisfactorily meet the present standard specifications for Portland Cements for soundness.

(H) Fineness and Sieve Analysis.

Of the blended cements, those containing 30 per cent of sand most nearly approximate the Portland Cements in fineness and gradation of size of particles.

CONCLUSIONS

Portland Cements, of a fineness sufficient to pass a No. 200 sieve, may be blended as much as 40 per cent. by weight, with quartz sand, the latter of a fineness sufficient to pass a No. 65 sieve but not fine enough to permit more than 20 per cent to pass a No. 200 sieve, and the resulting blended cement will satisfactorily pass the requirements of the present standard specifications for Portland Cement of the American Society for Testing Materials.

Quartz sand is a satisfactory substitute for the inert clinker particles in Portland Cement in maintaining the present physical characteristics of the latter, when used in amounts not to exceed 30 per cent, by weight.

Note: It is obviously impracticable to manufacture blended cements commercially in the manner followed in this investigation. It was thought to be feasible, however, to accomplish this end by incorporating the sand in the cement just prior to final grinding. Such procedure, it was thought, would have several advantages over the methods used here. It was thought that the reduction of the cement clinker in fineness much in excess of that attained at present would result and also that a more thorough mixing of the sand and cement would be accomplished than by any other method. With a view of ascertaining to what extent these assumptions are correct and also to what extent the blending of Portland Cement with quartz sand may be carried, the tests outlined under Series II were made. These tests are described in subsequent pages of this report.

SERIES II

DESCRIPTION

This series comprises two Divisions, called for convenience A and B. Each of these Divisions was made by mixing some of the banding sand before described with the cement as taken from the storage bins, making no attempt to remove the larger particles from the cement first, and grinding the mixture in a tube mill until a predetermined proportion of the mixture would pass through a No. 200 sieve. In Division A this proportion was 95%, while in Division B it was 85%. In all other respects these two Divisions are alike, and the subscripts, as in Series I, indicate the percentage of sand in the blended cement. Atlas Portland Cement was the only cement used in this Series. Each of the resulting blended cements were intended to have the same percentage of fineness. This result was attained only to a limited extent, as it was difficult to determine the time required for grinding. However, the variation in fineness is so slight as not to influence the results appreciably. (See Table XX.)

PURPOSE

The purpose in view in making up this Series was to determine whether further grinding would increase the quantity of active material in the cement by enough to compensate for the decrease in strength caused by adding sand to the cement, and if so to what extent sand could be added in this way without too far decreasing the resulting strength. The two Divisions,A and B, were made in order that a comparison might be made between cements having the same composition, and differing only in the amount of grinding to which they had been subjected.

PROCEDURE

The cement was used as taken from the storage bins, merely being sifted through a No. 20 sieve to remove the large lumps. To it was added the desired quantity of the banding sand. The mixture was then placed in the tube mill and ground until, by trial, the desired percentage would pass the No. 200 sieve.

The tests made on each of the cements in this Series were the same as those outlined under Seris I. The results follow.

RESULTS OF TESTS

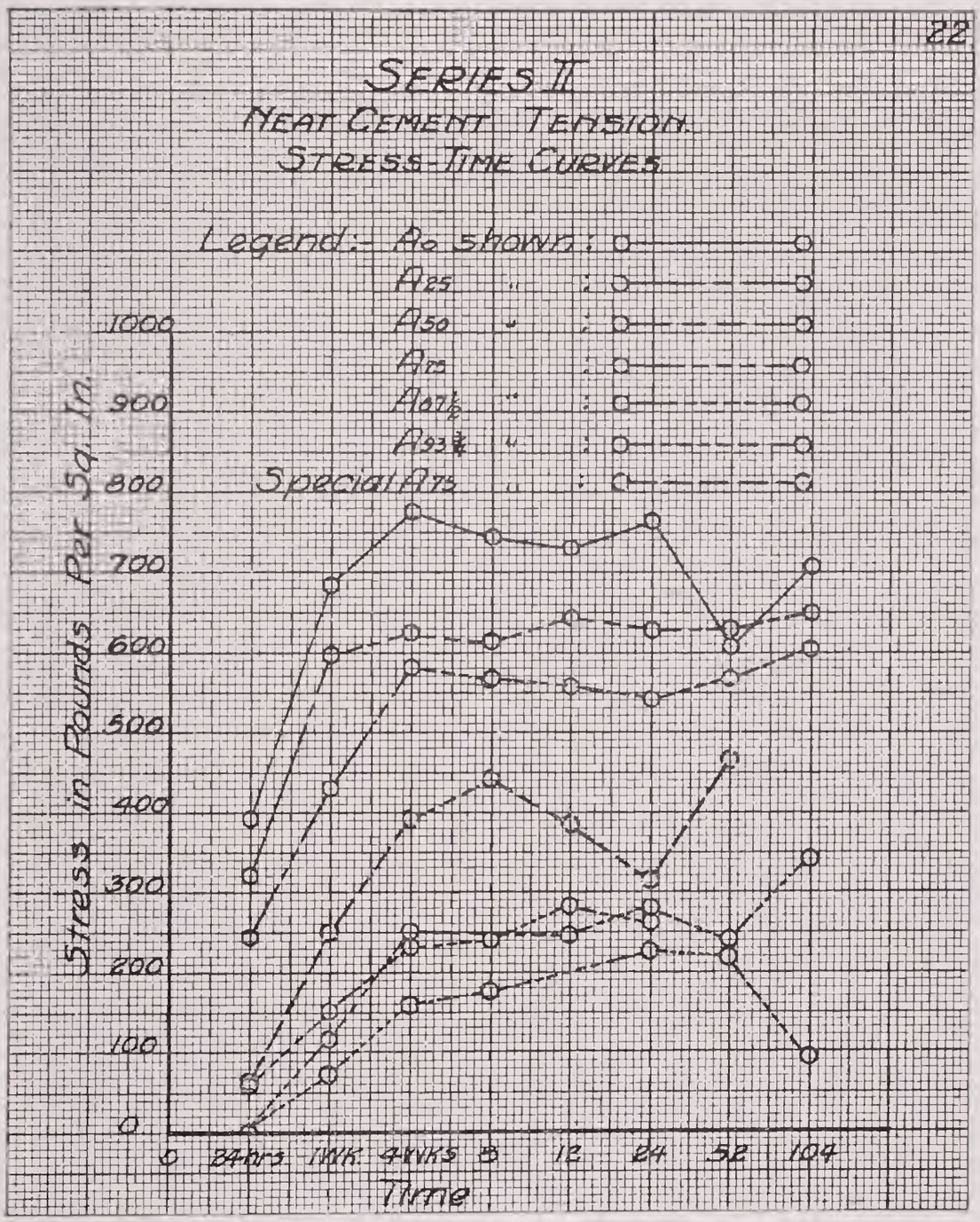
Note. It is interesting to observe that in both Divisions every cement listed passed satisfactorily the "pat" or soundness test, showing that a very small percentage of active particles will serve to hold the inert particles together, though not necessarily giving strength to the aggregate. This would seem to sound a warning against the not infrequent practice of accepting a cement on the soundness test alone, and to indicate the necessity for some tests of strength in connection with the soundness test.

(A) Neat Cement In Tension.

On Curve Sheet No. 22 are plotted the results obtained by testing the neat cement specimens of Division A. (See Table E, Appendix A.) It will be noted that only the first two cements, A_0 and A_{25}, meet the requirements of the standard specifications of the American Society for Testing Materials (1916), which are 175, 500 and 600 pounds at 24 hours, one week and four weeks respectively, though the A_{50} cement falls but little short of the requirements. Each of these two cements attains its maximum strength within 12 weeks, cement A attaining the greatest strength, as would be expected.

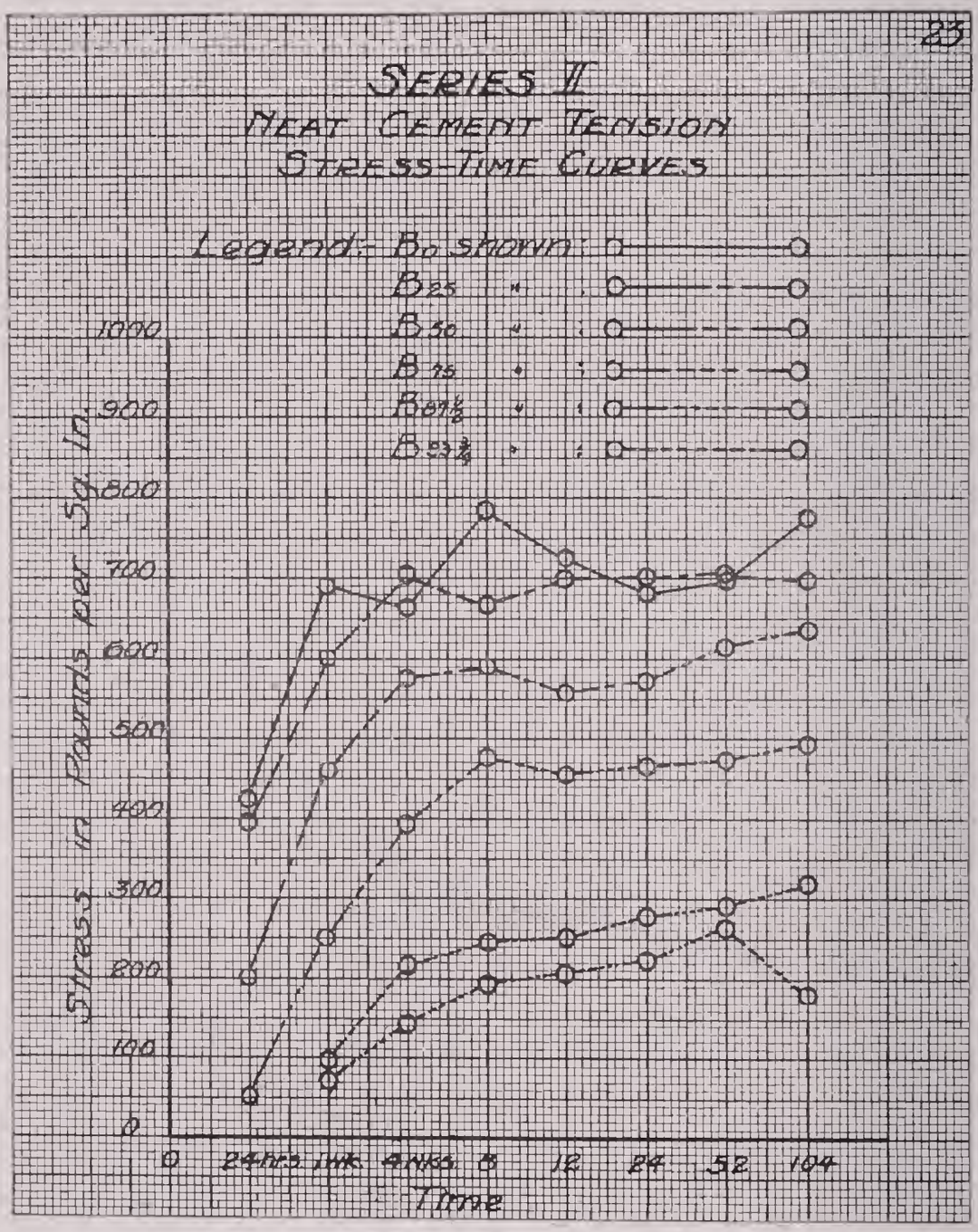
The A_{75}, $A_{87\ 1/2}$, and $A_{93\ 3/4}$ cements, while far below the requirements of the standard specifications, show a good increase in strength with age, and their strengths as compared to the A cement are not reduced in the same proportion as their cement content.

The $A_{96\ 7/8}$ cement shows practically no strength at any age, showing that there is a limit beyond which the decrease in strength is greater than the decrease in cement content.


22
SERIES II
NEAT CEMENT TENSION.
STRESS-TIME CURVES.
Legend:- A0 shows :
A25 "
A50 "
A75 "
A87½ "
A93¾ "
Special A75 "
Stress in Pounds per Sq. In.
1000
900
800
700
600
500
400
300
200
100
0
0
24 hrs
1WK.
4WKS
8
12
24
52
104
Time

Curve Sheet No. 23 shows the results for the tension tests on neat cement specimens in Division B. (See Table E, Appendix A.) The discussion of curve sheet No. 22 will apply with equal force to this sheet.

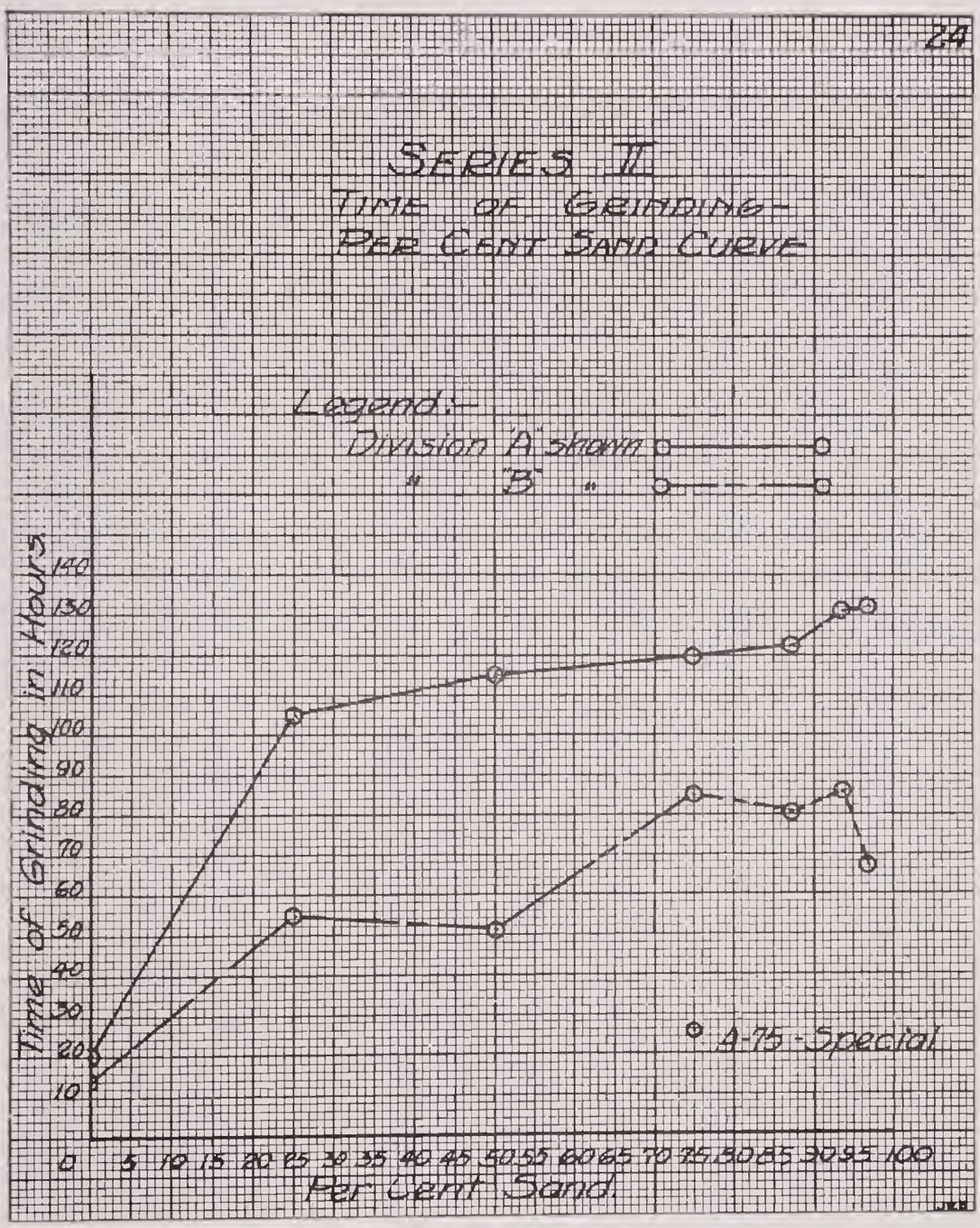
By a comparison of curve sheets 22 and 23 it is seen that the B cements run in general higher in strength than



the corresponding A cements, although the A cements were more finely ground. It will also be noted, from an examination of Table E, Appendix A, that cement A_{75}*, which was a special batch from which only the neat tension specimens were made, runs stronger than A_{75} but weaker than B_{75}.

(B) Time of Grinding.

Curve Sheet No. 24, showing the relation between time of grinding and per cent of sand, is introduced here, and it is interesting to note that cement B_{75}, with a greater strength than either A_{75} or A_{75}*, lies between them in time of grind-



ing, while the B curve lies everywhere below the A curve. No explanation is attempted at this time of these facts, owing to the meagerness of the data at hand, but it is hoped that more experiments will throw more light on this phase of the subject.

It will be noticed by reference to curve sheet No. 24 that the time of grinding does not increase proportionately to the per cent of sand after the 25 per cent point is passed, showing that the presence of the sand facilitates the fine grinding of the cement clinker.

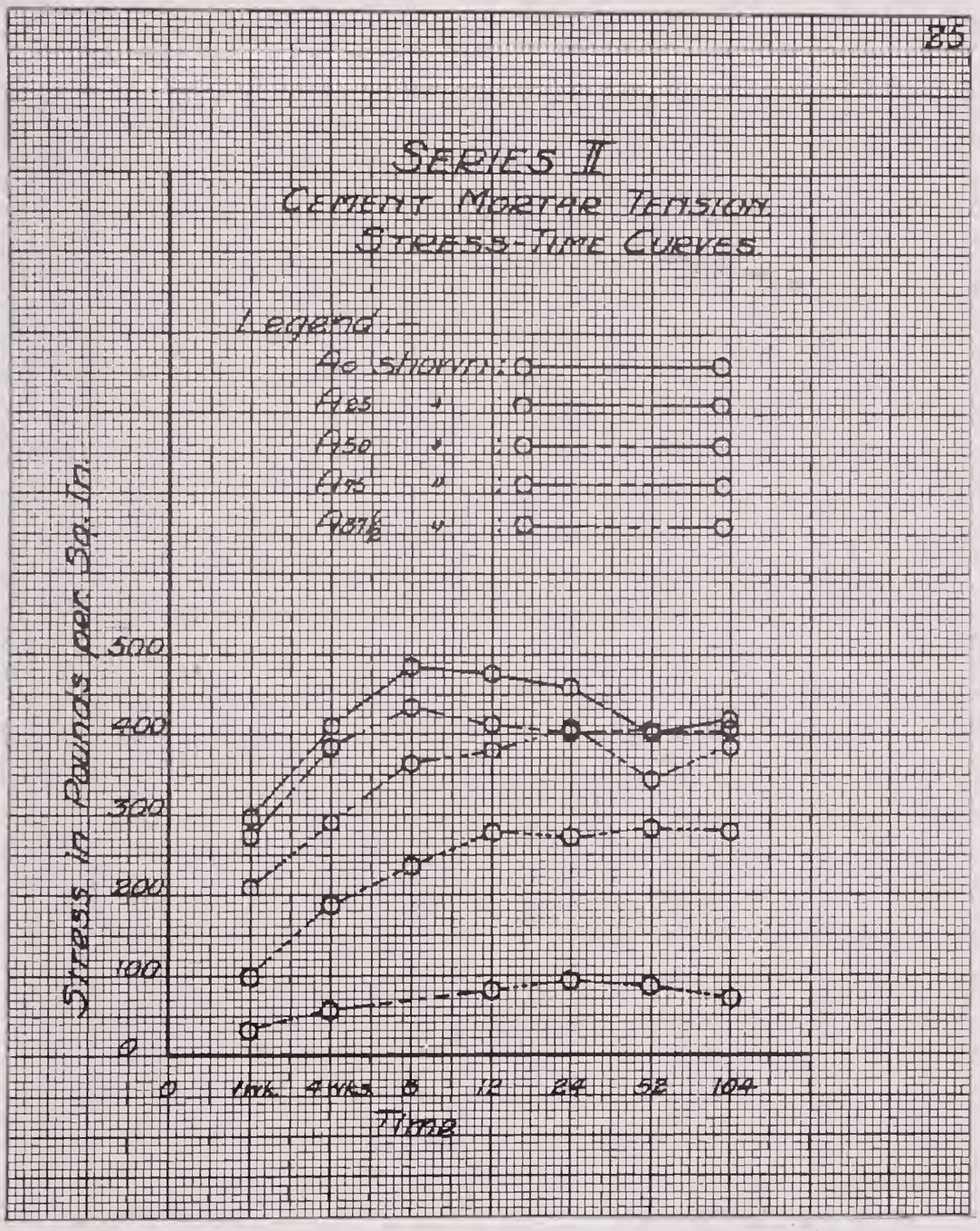
The tabulated values from which curve sheet No. 24 was plotted will be found in Table XX, page 73.

(C) Cement Mortar In Tension.

On curve sheet No. 25 are plotted the results of tension tests of 1:3 mortar specimens in Division A. (See Table F, Appendix A.) As with the neat cements, only the first two cements, A and A_{25}, satisfy the requirements of the standard specifications of the American Society for Testing Materials, which are, for 1917, 200 and 300 pounds at the ages of 1 week and 4 weeks respectively, but cement A_{50} falls only a little below these requirements.

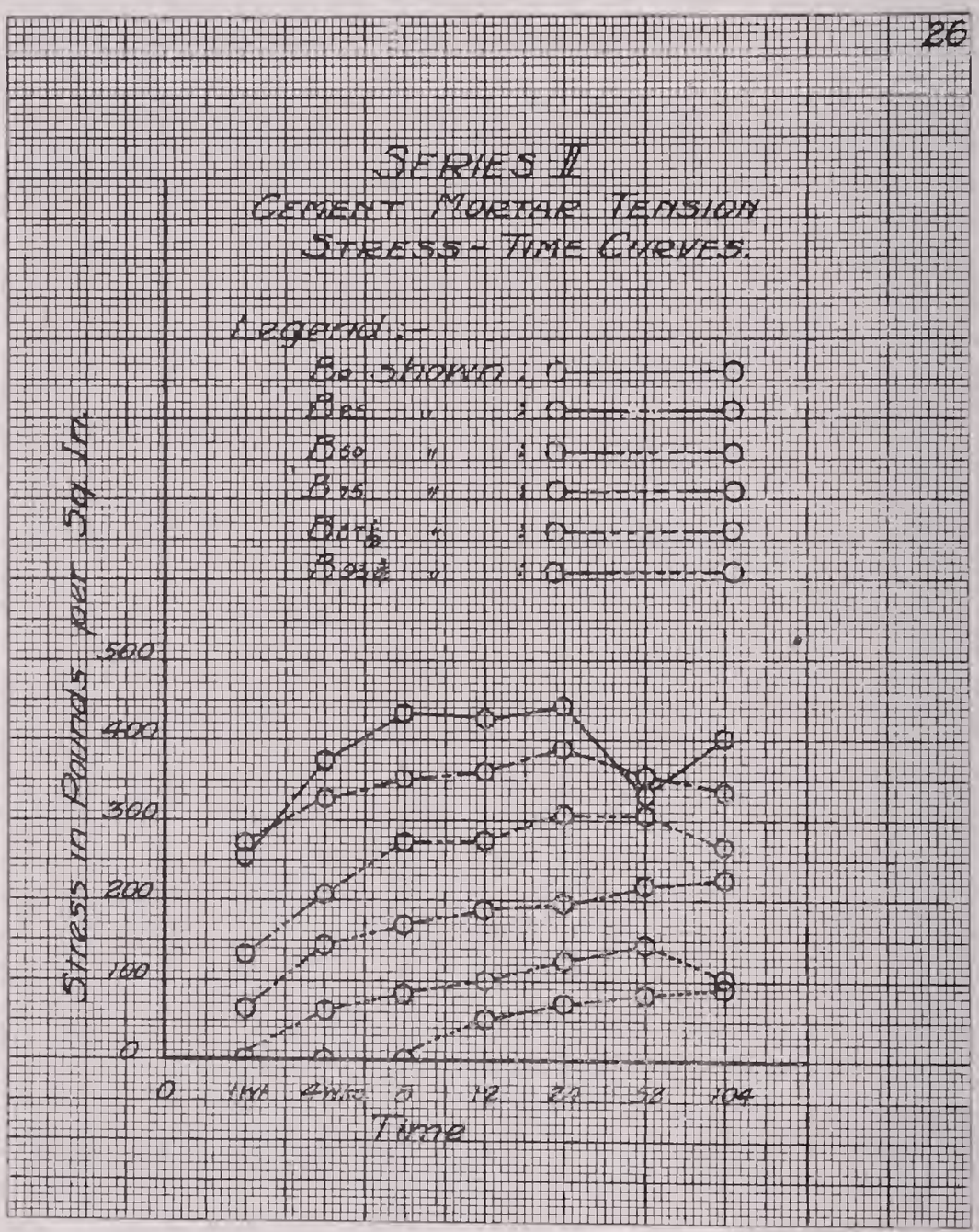
Cements A_{75} and $A_{87\ 1/2}$, while far below the required strengths, show a good increase in strength with age, and their strengths are not reduced, as compared to cement A, in proportion to the reduction in their cement content.

Cements $A_{93\ 3/4}$ and $A_{96\ 7/8}$ show no strength at any age, indicating a lower limit for the blending process than obtains for the neat cements, as would naturally be expected.


25
SERIES II
CEMENT MORTAR TENSION
STRESS-TIME CURVES
Legend:—
As shown:
As 1
As 2
As 3
As 1/2
Stress in Pounds per Sq. In.
500
400
300
200
100
0
0
1wk.
4 wks.
8
12
24
52
104
Time

Curve Sheet No. 26 shows the results of tension tests on mortar specimens of Division B. (See Table F, Appendix A.)

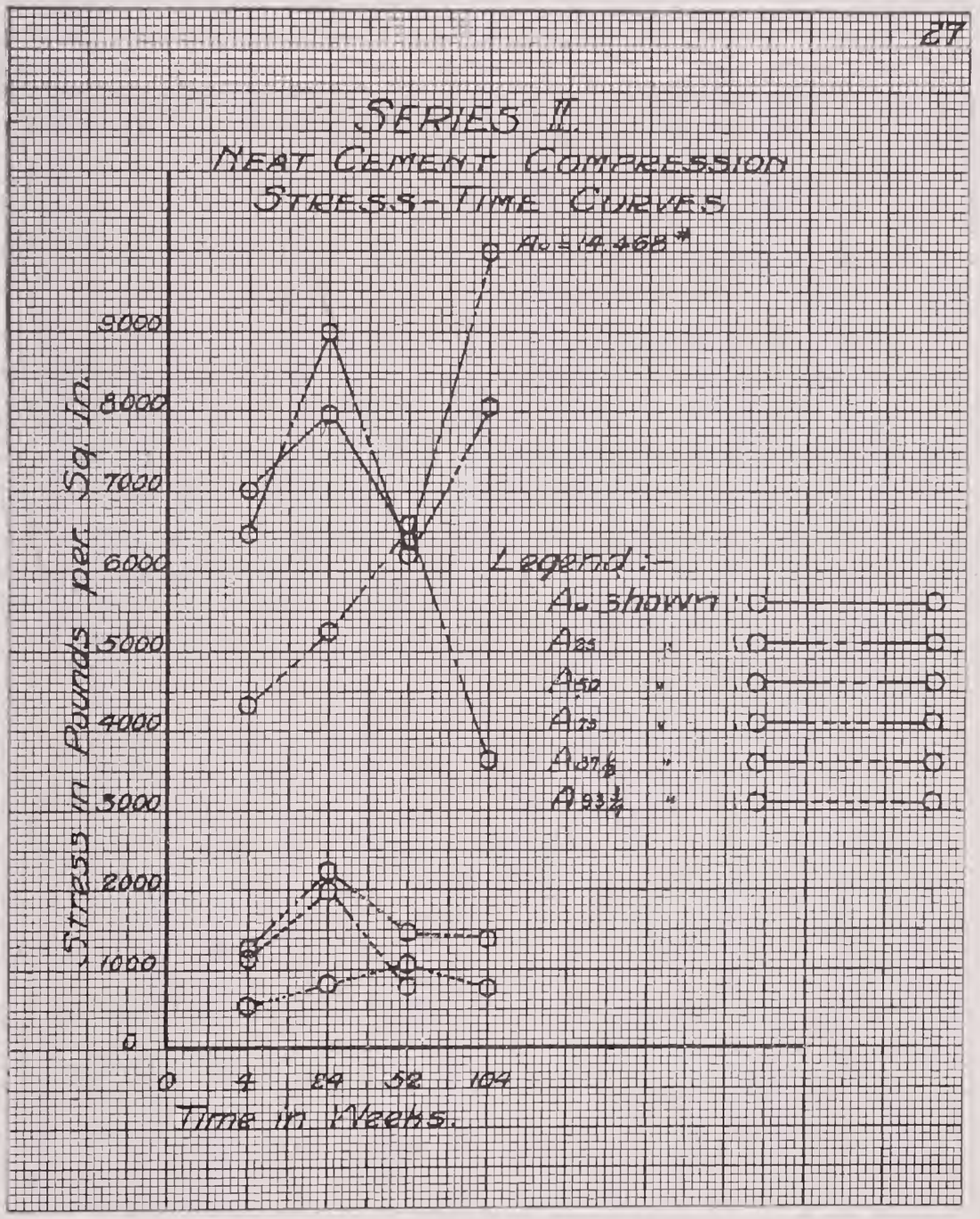
As in Division A, the first two cements, B and B_{25}, meet the requirements of the standard specifications, but in this Division cement B_{50} falls considerably below the requirements.



A comparison of curve sheets 25 and 26 shows that the cements of Division B are weaker than the corresponding cements of Division A. This is what would naturally be expected, but is just the reverse of the relationship noted in the neat tension tests, and will be left unexplained for the present.

(D) Neat Cement In Compression.

Curve Sheet number 27 shows the results obtained by testing neat cement specimens of Division A in compression. (See Table G, Appendix A.) There is much the same irregularity to be observed in this series as in Series I, as



for example the drop in the A_0 line from 24 to 52 weeks, its extremely high value at 104 weeks, the unusually high value of A_{25} at 24 weeks, and the large drop of the A_{50} line from 52 to 104 weeks.

As noted under Series I, this test is not a standard test, and hence no direct criterion exists by which to judge re-

sults, but if we use 5000 pounds per square inch, (the usual limit of safety for large buildings), as a standard, it is seen that A_0 and A_{25} satisfy it, and that A_{50} almost satisfies it at 4 weeks and entirely so at 24 and 52 weeks.

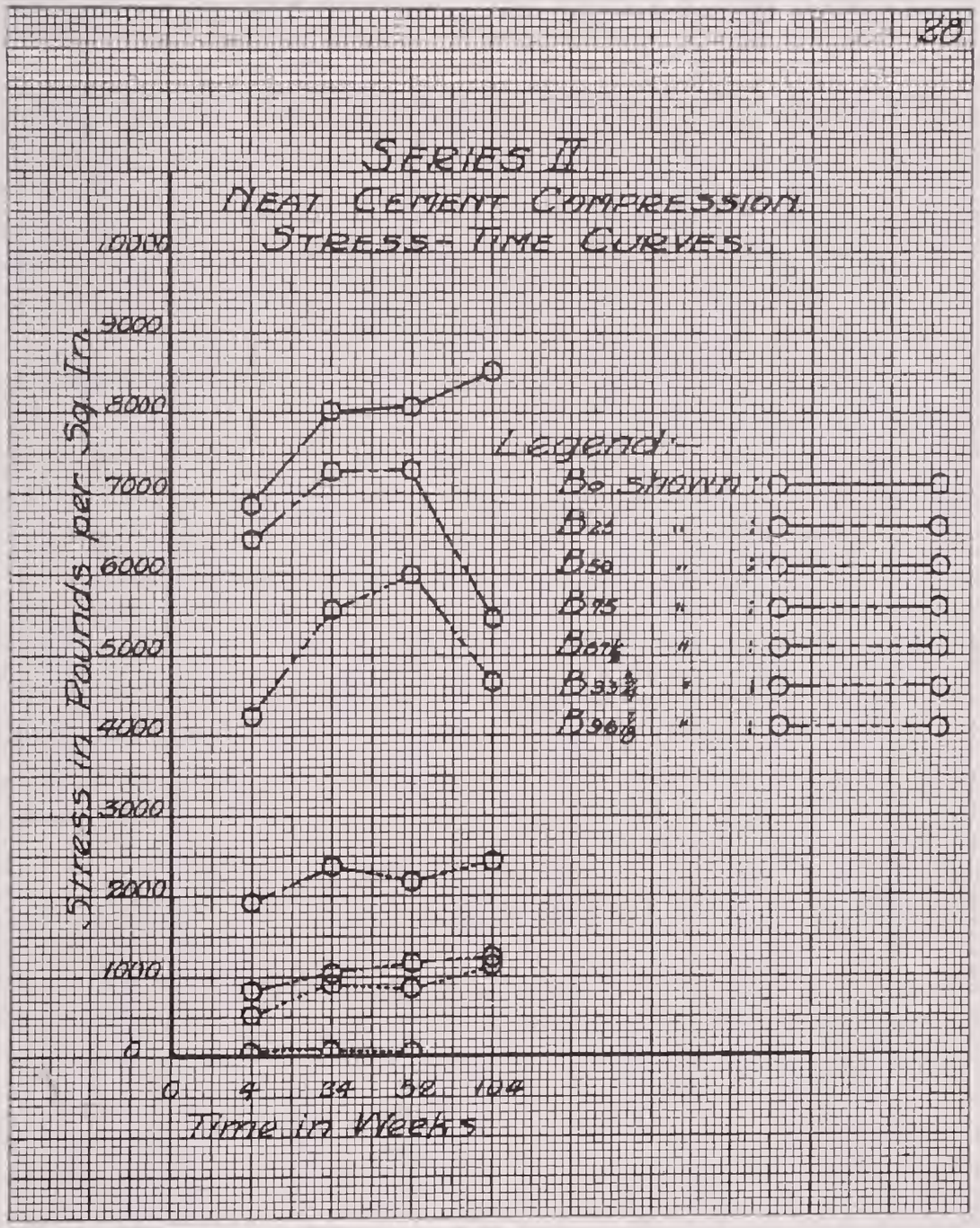
A_{75} and $A_{87\ 1/2}$ furnish, in their 52-week tests, two of the unaccountable sudden drops experienced in the compression tests.

$A_{93\ 3/4}$ shows a good increase in strength with age, and all of the cements down to and including this cement show a decrease in strength as compared to A_0 which is less than the decrease in cement content.

$A_{96\ 7/8}$ has practically no strength at any age, as in the tension tests.

Curve Sheet number 28 shows the results of the neat compression tests in Division B. (See Table G, Appendix A.) The discussion of curve sheet 27 will apply to this sheet also. Notice the drops on the B_{25} and B_{50} lines.

A comparison of curve sheets 27 and 28 shows much less difference between the corresponding cements of the two divisions than was observed under the tension tests, but the superiority seems to rest with the A division if either way, which agrees with the results observed under the mortar tension tests.

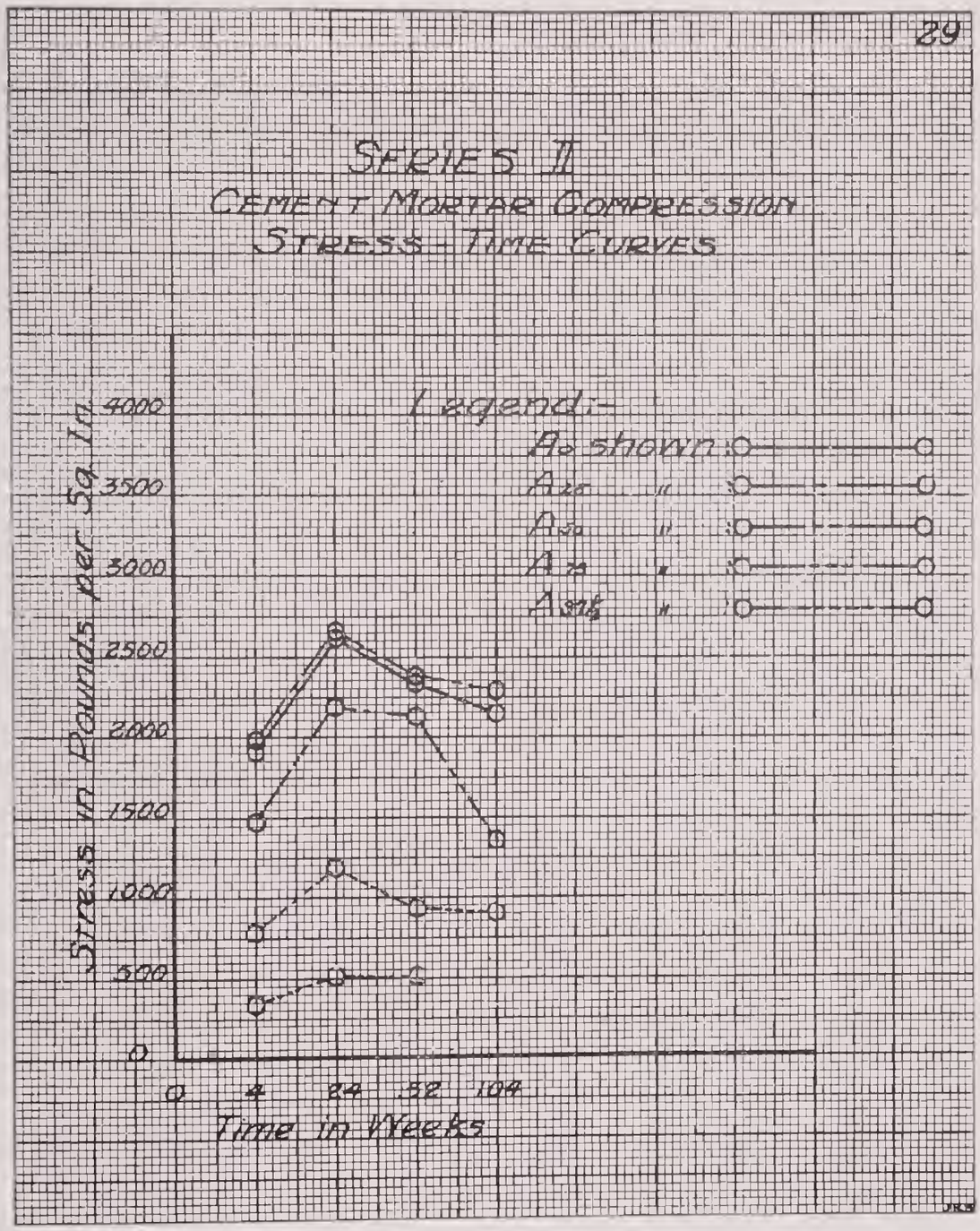

28
Series II
Neat Cement Compression
Stress-Time Curves.
Stress in Pounds per Sq. In.
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
4
24
52
104
Time in Weeks
Legend:-
B as shown:
B21 "
B50 "
B75 "
B67½ "
B33⅓ "
B26⅔ "

(E) Cement Mortar In Compression.

Curve Sheet number 29 shows the results obtained by testing in compression specimens of 1:3 mortar made with the cements of Division A. (See Table H, Appendix A.)

This table shows the most uniform set of results obtained in any of the series of compression tests in the entire investigation, yet even here the strength falls off after attaining its maximum at 24 weeks.

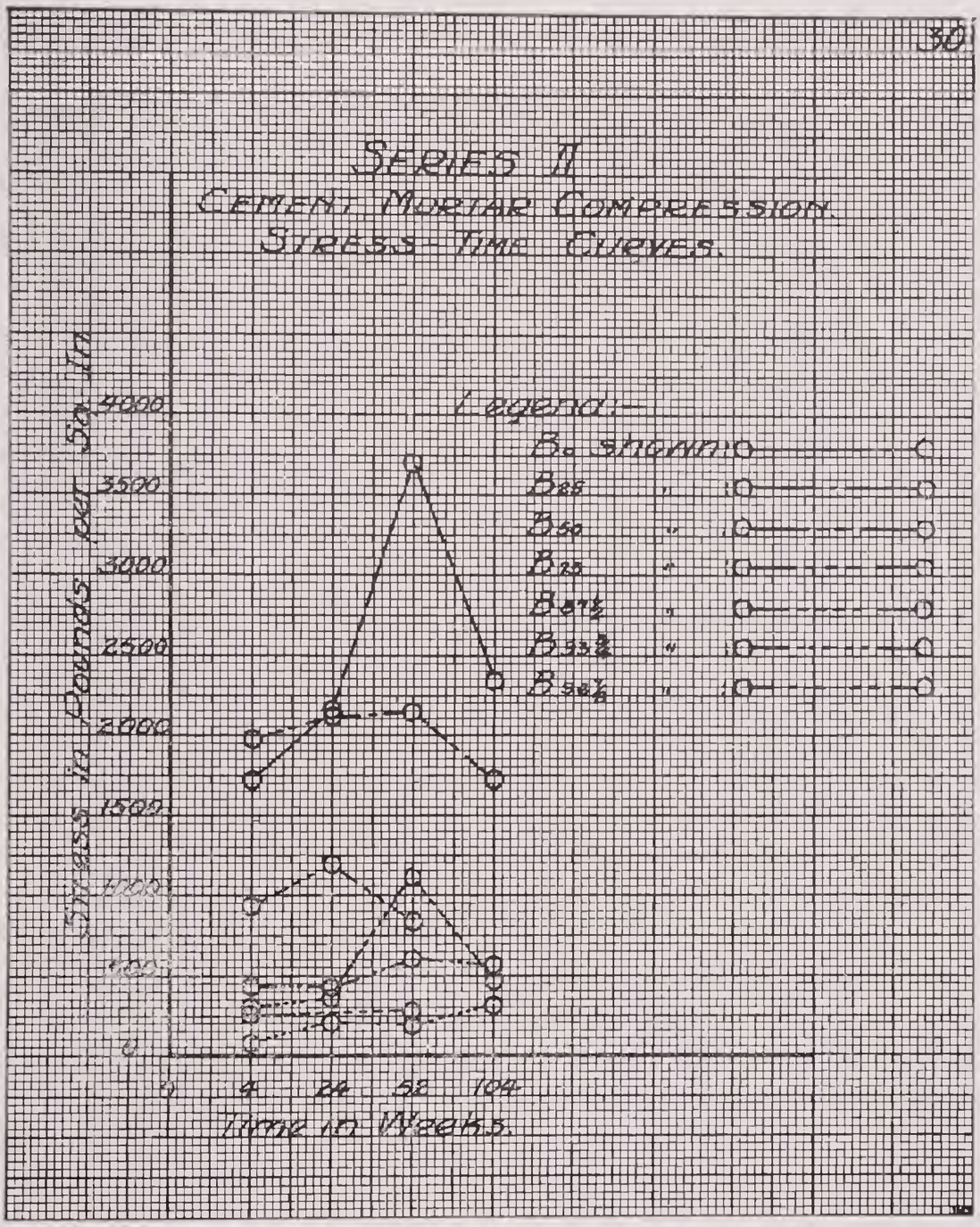
None of the cements satisfy the requirements proposed by the American Society of Testing Materials, namely, 1200 and 2000 pounds per square inch at 1 and 4 weeks respectively, but the first three cements, A_0, A_{25}, and A_{50},all satisfy the latter figure at 24 weeks. A_{75} and $A_{87\ 1/2}$ do not satisfy the requirements, but show a good increase in strength with age, and a decrease in strength as compared to A_0 which is less than the decrease in cement content. $A_{93\ 3/4}$ and $A_{96\ 7/8}$ show practically no strength at any age, which agrees with the mortar tension tests.


29
SERIES II
CEMENT MORTAR COMPRESSION
STRESS - TIME CURVES
Legend:-
As shown
A 26 "
A 50 "
A 74 "
A 97½ "
Stress in Pounds per Sq. In.
4000
3500
3000
2500
2000
1500
1000
500
0
0
4
24
52
104
Time in Weeks

Curve Sheet 30, which shows the results of the mortar compression tests for Division B, exhibits more of the striking irregularities of the compresson tests, particularly the very high value of $B_{87\ 1/2}$ for 52 weeks, and the high values for $B_{96\ 7/8}$.

Here again none of the cements meet the proposed requirements of the American Society of Testing Matrials at 4 weeks, but the first two, B_0 and B_{25}, meet them at 24 weeks. None of the other cements meet the requirements, but all show good increase in strength with age, and a reduction of strength compared to B_0 less than the reduction in cement content.

A comparison of curve sheets 29 and 30 shows the A cements to be superior down to and including A_{75}, but in the weaker cements the B division leads. As heretofore stated, no attempt will be made in this report to explain this, but it is hoped that further experimentation may serve to throw some light on the matter.


SERIES II
CEMENT MORTAR COMPRESSION.
STRESS - TIME CURVES.
Legend:—
B. shown
B28 "
B50 "
B25 "
B37½ "
B33⅓ "
B30⅓ "
Stress in Pounds per Sq. In.
4000
3500
3000
2500
2000
1500
1000
500
0
4
24
52
104
Time in Weeks.

(F) Normal Consistency.

Curve Sheet number 31 shows the amount of water required to bring each cement to normal consistency. (See Table XIX) It would naturally be expected that the cements in Division A would require more water than those in Division B, due to the finer grinding, and the curves show this to be a fact in every case.

The general trend of the A curve is slightly upward, (disregarding the extremely high value for A_{75} for which no cause can be assigned), which shows that the grinding was so thorough as to actually increase the amount of water needed for hydration of the cements containing the higher percentages of sand, while the B curves is practically horizontal, showing that in this division the grinding was just about sufficient to maintain the amount of water practically a constant.

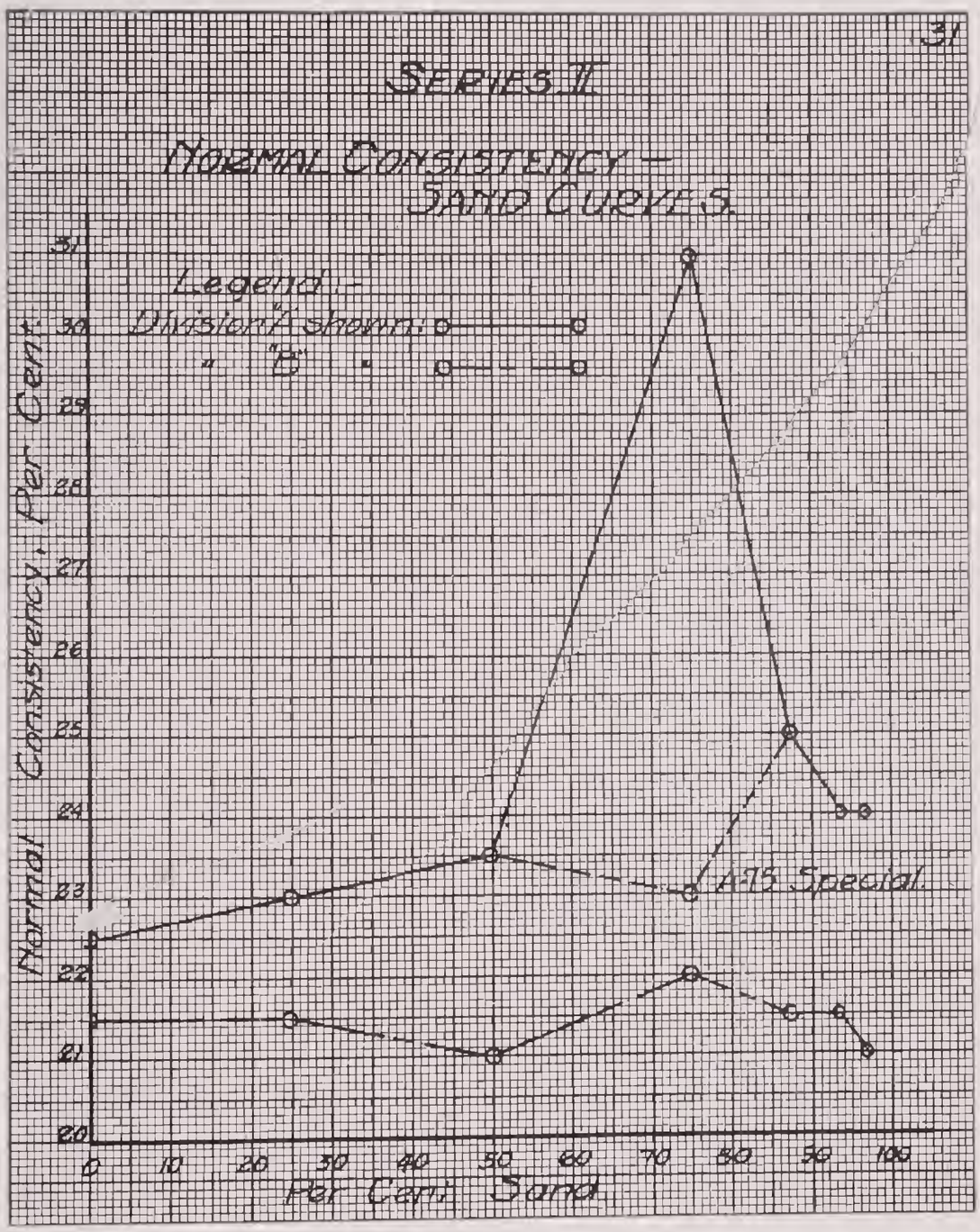
The percentage of water required for the mortar specimens was in each case taken from the standard conversion tables of the specifications of the United States Government for Portland Cement Mortar, and therefore the characteristics above noted apply to mortar as well as to cement paste.

TABLE XIX

Series II

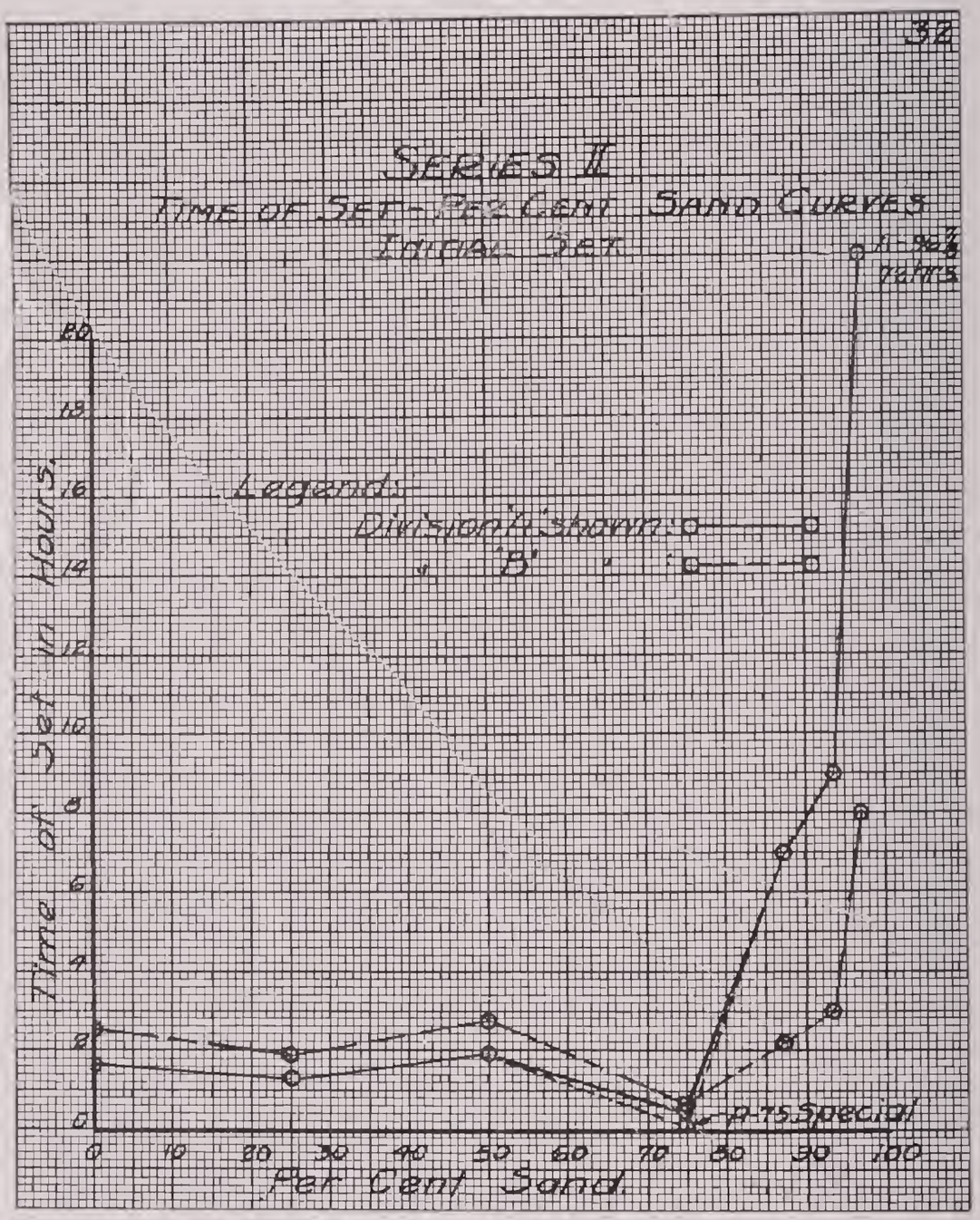
TIME OF SET AND NORMAL CONSISTANCY.

	Time of Set By Vicat				Normal Consistency	
	Initial		Final			
	Hours	Minutes	Hours	Minutes	Neat paste Per Cent	1:3 Sand Mortar Per Cent
A_0	1	44	4	37	22 5	10.25
A_{-25}	1	20	3	05	23.0	10.3
A_{-50}	1	55	4	15	23.5	10.4
A_{-75}		27	1		31.0	10.7
$A_{-87\ 1/2}$	7		16	30	25.0	10.7
$A_{-93\ 3/4}$	9(*)		17+		24.0	10.5
$A_{-95\ 7/8}$	72		164		24.0	10.5
A_{-75}-*Special		10	1	30	23.0	
B_{-0}	2	33	4	16	21.5	10.1
B_{-25}	1	52	3	14	21.5	10.1
B_{-50}	2	41	3	50	21.0	10.0
B_{-75}		38	6	30	22.0	10.2
$B_{-87\ 1/2}$	2	11	7	13	21.5	10.1
$B_{-93\ 3/4}$	3		11	15	21.5	10.1
$B_{-96\ 7/8}$	7	51	26	50	21.0	10.0

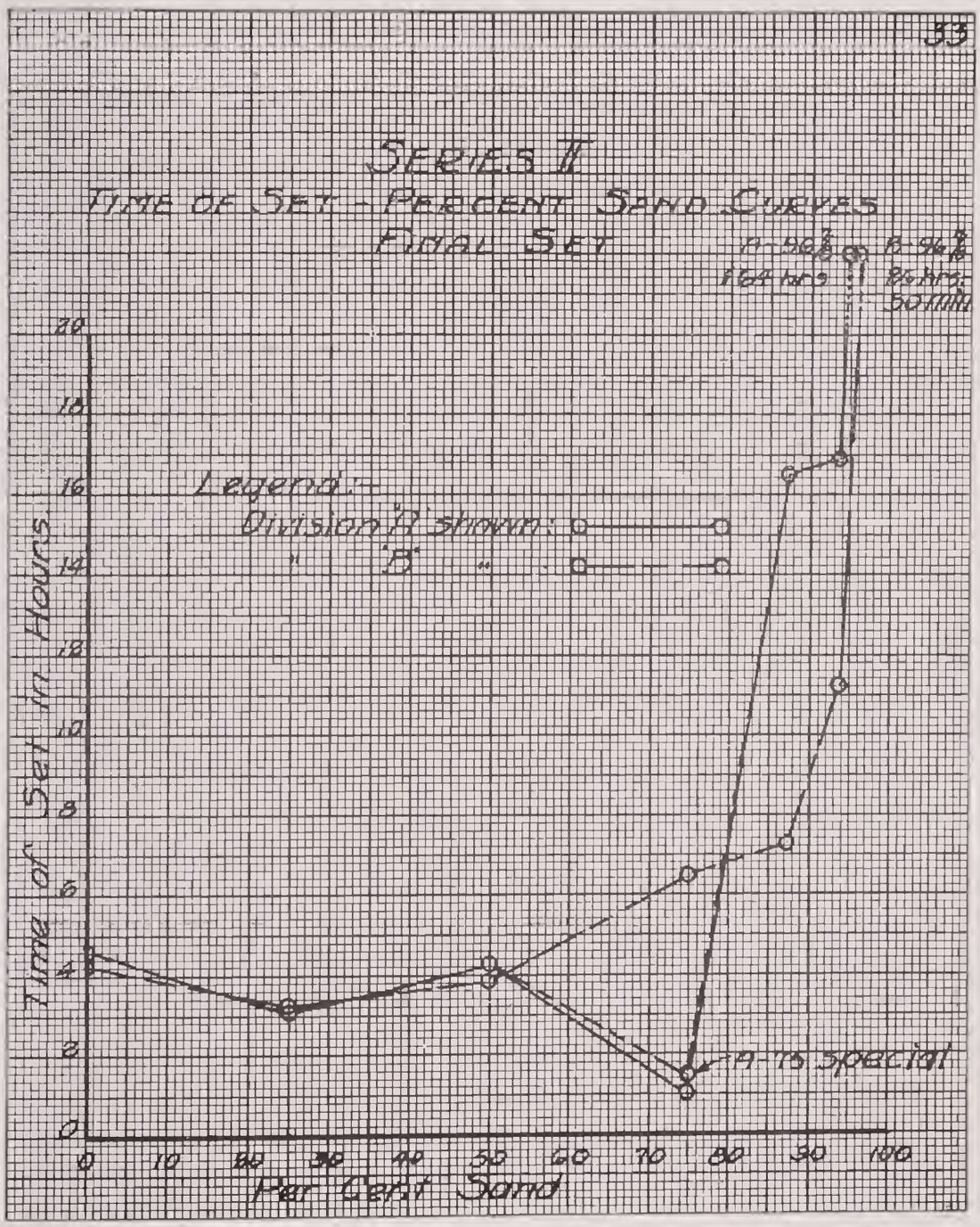

SERIES II.
NORMAL CONSISTENCY —
SAND CURVES.
Legend:—
Division "A" shown: o——o
" "B" " o- - -o
A-75 Special.
Normal Consistency, Per Cent.
31
30
29
28
27
26
25
24
23
22
21
20
0
10
20
30
40
50
60
70
80
90
100
Per Cent. Sand.

(G) Time of Setting.

The time required to produce initial and final setting of each of the cements was determined with the Vicat apparatus, and is shown on curve sheets 32 and 33, and tabulated in Table XIX.



There is a slight decrease in time of set for the 25 per cent sand cements, increasing again until the 50 per cent sand cement requires about the same time as the cement itself, then a decrease for all but one of the 75 per cent samples, with a sharp increase for higher percentages.


33
SERIES II
TIME OF SET - PERCENT SAND CURVES
FINAL SET
Legend:-
Division "A" shown:
" "B" "
Time of Set in Hours.
Per Cent Sand
A-96 hrs. 164 hrs.
B-96 hrs. 80 hrs. 50 min.
A-75 Special

(H) Constancy of Volume.

The usual tests, normal and accelerated, for the determinations of soundness were made. The standard methods suggested by the American Society of Civil Engineers were followed in these tests. The specimens were observed for periods of one year and in every instance the standard specifications were fulfilled. Each of the specimens remained true and sound throughout this entire period.

TABLE XX

Series II

COMPOSITION TABLE.

Cement Serial No.	Wt. of Batch Ground in pounds		Increase in wt. in lbs.	Final Percentage		Sieve Analysis Percent Retained on Sieves			Time of grinding in tube mill	
	Cement	Sand	See Note*	Cement	Sand	No. 100	No. 150	No. 200	Hours	Minutes
A_0	24	0		100	0	0	1.2	6.7	20	
A_{25}	18	6		75	25	0	Trace	4.7	105+	20
A_{50}	12	12		50	50	0	Trace	5.0	114	20
A_{75}	6	18		25	75	0	1.2	7.2	120	
$A_{87\ 1/2}$	3	21		12.5	87.5	0	Trace	5.0	122	
$A_{93\ 3/4}$	1.5	22.5	0.61	6.1	93.9	0	‡	1.6	131	30
$A_{96\ 7/8}$	0.75	23.25	1.11	3.0	97.0	0	‡	1.6		
A_{75}*Special	1.75	5.25		25	75	0	Trace	1.7	25	40
B_0	24	0		100	0	‡	4.2	11.6	13	45
B_{25}	18	6	0.11	74.6	25.4	0	1.0	7.6	55	15
B_{50}	12	12	0.22	49.5	50.5	‡	4.0	15.0	51	
B_{75}	6	18	0.33	24.7	75.3	†	5.0	16.6	84	40
$B_{87\ 1/2}$	3	21	0.61	12.2	87.8	†	4.0	16.2	81	
$B_{93\ 3/4}$	1.5	22.5	0.61	6.1	93.9	†	2.2	12.2	86	40§
$B_{96\ 7/8}$	0.75	23.25	0.86	3.1	96.9	0	3.6	15.6	66	55

*Note:—Increase in weight in pounds due to wearing of pebbles in tube mill during grinding.

‡Barely a trace. †A few sand grains. §A small amount leaked out of jar.

(I) Fineness and Sieve Analysis.

The sieve analysis of the different cements are shown in Table XX. It will be noticed that the percentage retained on the No. 150 and No. 200 sieves are practically uniform for each division. As before stated, it was intended that in Division A 95% should pass through the No. 200 sieve, and for Division B 85% should do so. Practical difficulties prevented the absolute attainment of this end, but the results are so closely in agreement that for all practical purposes they may be said to have been accomplished.

(J) Chemical Analysis and Specific Gravity.

The chemical analyses recorded in Table XXI are partly laboratory determinations and partly determinations arrived at by computation. The Portland Cement and the Banding Sand were analyzed by Mr. R. P.Rinker, Chemist for the Missouri Bureau of Geology and Mines, through the courtesy of Mr. H. A. Buehler, Director. An analysis of the cement was also furnished by the cement company. The results obtained by Mr. Rinker and those furnished by the cement company are so nearly identical that only those of the former are shown. The analyses of the various blended cements are the results of combining the analysis of the banding sand with that of the Portland Cement in the ratio of the combination of sand to cement.

TABLE XXI

Series II

CHEMICAL ANALYSIS AND SPECIFIC GRAVITY.

Analysis of Cement

Cement Serial Number	Ignition Loss	Percentage of:							Sp. Gr.	
		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Total	Computed	Determined
A_0	1.80	21.98	2.57	5.89	63.32	3.00	1.50	100.06	3.184	3.095‡
A_{25}	1.43	41.10	2.04	4.59	47.51	2.25	1.15	100.07	3.058	2.981*
A_{50}	1.06	60.32	1.44	3.33	31.68	1.50	0.75	100.08	2.933	2.850*
A_{57}	0.69	79.49	0.87	1.99	15.86	0.75	0.38	100.03	2.806	2.740*
$A_{87\ 1/2}$	0.50	89.04	0.59	1.34	7.94	0.38	0.19	99.98	2.743	2.712*
$A_{93\ 3/4}$	0.41	93.94	0.45	1.01	3.90	0.19	0.09	99.98	2.712	2.660*
$A_{96\ 7/8}$	0.36	96.34	0.38	0.84	1.94	0.09	0.04	99.99	2.696	2.654*
A_{75}* Special	0.69	79.49	0.87	1.99	15.86	0.75	0.38	100.03		*
B_0	1.80	21.98	2.57	5.89	63.32	3.00	1.50	100.06	3.184	3.095†
B_{25}	1.42	41.49	2.00	4.57	47.21	2.21	1.13	100.03	3.058	2.959*
B_{50}	1.06	60.59	1.44	3.28	31.35	1.49	0.75	99.96	2.933	2.863*
B_{75}	0.68	79.79	0.87	1.97	15.65	0.74	0.37	100.07	2.806	2.738*
$B_{87\ 1/2}$	0.50	89.28	0.58	1.32	7.77	0.37	0.18	100.00	2.743	2.696*
$B_{93\ 3/4}$	0.41	93.94	0.45	1.01	3.90	0.19	0.09	99.98	2.712	2.690*
$B_{96\ 7/8}$	0.37	96.28	0.38	0.85	2.04	0.09	0.05	100.06	2.696	2.658*
Banding Sand	0.32	98.66	0.31	0.69	0.04			100.02	2.681	2.681‡

‡Laboratory Analysis. *Computed Analysis.

SUMMARY

The foregoing observations may be briefly summarized as follows:—

(A) Neat Cement In Tension.

The blended cements, up to 75 per cent sand, show about the same rate of increase in strength as the cement itself.

The 25 per cent blended cement meets the standard specifications satisfactorily, and the 50 per cent blended cement nearly meets them; the other blended cements fall far short of meeting them. It seems likely that a blended cement containing about 40 per cent of sand would meet the requirements satisfactorily.

(B) Time of Grinding.

The relationship between time of grinding and resulting strength, if any exists, is not demonstrated by these experiments.

Apparently the presence of sand with the cement in the tube mill facilitates the fine grinding of the mixture of sand and cement.

(C) Cement Mortar In Tension.

The discussion of neat cement in tension will apply here, with the exception that the 50 per cent blended cement of the B Division falls considerably short of the standard specifications.

(D) Neat Cement In Compression.

The results obtained are not entirely satisfactory, owing to lack of uniformity.

The 25 per cent blended cements meet the proposed requirements for strength, and the 50 per cent blended cements nearly meet them, indicating, as in the tension tests, that a 40 per cent blended cement would probably meet the requirements.

(E) Cement Mortar In Compression.

Portland cement is only slightly stronger than the 25 per cent blended cements.

None of the cements meet the requirements of the standard specifications, though up to the 50 per cent blended cements they all very nearly meet them.

Note: Throughout the investigation, great irregularity exists in the relationship of the two divisions, some tests favoring the more finely ground cements and others the reverse. This seems to present a good field for further experimentation, and no attempt is made at the present time to explain it.

(F) Normal Consistency.

With one exception, the normal consistency of the cements tested varies within very narrow limits, and apparently no direct law of variation can be stated.

(G) Time of Setting.

Within the scope of this investigation, Portland Cements differ widely in the time of setting.

Blended cements, having not more than 75 per cent of blending material, develop initial and final set more rapidly than do the Portland cements of which they are composed.

Blended cements, having more than 50 per cent of blending material, satisfy the requirements of the present standard specifications for the time of setting of Portland Cements.

(H) Constancy of Volume.

All of the cements tested in this series satisfactorily meet the present standard specifications for soundness. (See page 55).

(I) Fineness and Sieve Analysis.

The cements of each Division were sufficiently uniform in fineness to prevent the variations from affecting the results appreciably.

CONCLUSIONS

Quartz sand may be added to Portland Cement before final grinding to the extent of about 40 per cent by weight, and the resulting blended cement will, after sufficient grinding, satisfactorily pass the requirements of the present standard specifications for Portland Cement of the American Society for Testing Materials.

The presence of quartz sand with the cement clinker in a tube mill facilitates fine grinding of the latter.

The satisfaction of the present standard test for soundness of cement should not be depended on alone to qualify a cement for acceptance, but some tests for strength should also be made.

Note: It is felt that this series of tests does not completely determine the limit to which sand may be added to the cement clinker, nor the theoretical limit of grinding for the blended cements. A series of tests of cements blended as in Series II, but using the same percentages of blending material that were used in Series I would, it is felt, be of considerable interest; also a series of tests using some fixed percentage of blending material and varying th

ness of grinding would be exceedingly interesting, and would probably serve to clear up some of the uncertainties exhibited in this report as to the theoretical limit of grinding. The economic limit would of course depend not only on the strength of the resulting blended cement, but also on the cost of the cement and sand and of the labor involved in grinding.

It is hoped that further investigation may be conducted along these lines.

APPENDIX A

The tables in this appendix are condensations of the complete detailed tables of Appendix B, giving only the average values for each test. They were prepared with the idea of showing final results at a glance, and from them the curves embodied in the report were plotted.

Where a blank space occurs in a table, it signifies that no test was made, usually because the specimens were missing.

Where the word "No" occurs, it signifies that the specimens were tested and found to have no strength.

TABLE A.

Series I

AVERAGE RESULTS OF TENSION TESTS.

(Neat Specimens)

Pounds per Square Inch.

Serial Number	Age When Tested							
	24 hours	1 week	4 weeks	8 weeks	12 weeks	24 weeks	52 weeks	104 weeks
A_0	317	779	855	758	789	744	728	750
A_{10}	322	537	682	666	711	589	589	690
A_{20}	243	752	715	738	773	742	679	693
A_{30}	278	657	771	849	732	758	738	678
A_{40}	310	662	754	748	771	761	722	720
B_0	306	815	821	801	883	722	681	
B_{10}	366	666	699	792	708	678	616	679
B_{20}	332	733	859	735	792	743	565	672
B_{30}	259	651	763	774	702	741	730	707
B_{40}	265	547	655	777	711	693	681	689
C_0	393	686	779	758	745	636	572	585
C_{10}	301	630	758	700	681	608	434	472
C_{20}	306	610	622	614	703	630	512	540
C_{30}	178	591	607	711	607	660	588	572
C_{40}	200	511	637	706	644	648	618	566
Average of Averages								
$A_0 - B_0 - C_0$	335	760	818	772	806	701	660	668*
$A_{10} - B_{10} - C_{10}$	330	611	713	719	700	625	546	614
$A_{20} - B_{20} - C_{20}$	294	692	732	702	756	705	585	628
$A_{30} - B_{30} - C_{30}$	238	633	714	778	780	720	685	652
$A_{40} - B_{40} - C_{40}$	258	573	682	758	709	701	673	658

*B Specimens Missing.

For detailed results see Table 1, Appendix B.

TABLE B

Series I

AVERAGE RESULTS OF TENSION TESTS.

(Motar Specimens)

Pounds per Square Inch.

Number Serial	Age When Tested						
	1 week	4 weeks	8 weeks	12 weeks	24 weeks	52 weeks	104 weeks
A_0	186	289	325	346	310	247	261
A_{10}	338	427	461	508	486	396	367
A_{20}	272	405	459	417	452	402	325
A_{30}	225	358	393	440	433	377	348
A_{40}	201	341	360	349	351	331	287
B_0	197	339	369	384	369	355	
B_{10}	297	425	453	461	432	479	396
B_{20}	277	418	423	448	434	391	347
B_{30}	248	334	396	413	403	366	327
B_{40}	194	324	343	362	363	330	277
C_0	232	374	382	471	440	381	348
C_{10}	274	322	383	461	457	403	378
C_{20}	266	419	418	462	386	389	335
C_{30}	258	362	408	414	425	377	335
C_{40}	194	365	359	407	373	323	308
Average of Averages.							
$A_0 - B_0 - C_0$	205	334	359	400	373	331	305*
$A_{10} - B_{10} - C_{10}$	303	391	432	477	458	426	380
$A_{20} - B_{20} - C_{20}$	272	413	433	442	424	394	336
$A_{30} - B_{30} - C_{30}$	244	351	399	422	420	373	337
$A_{40} - B_{40} - C_{40}$	196	342	354	375	362	328	291

*B Specimens Missing.

For detailed results see Table 2, Appendix B.

TABLE C

Series I

AVERAGE RESULTS OF COMPRESSIVE TESTS.

(Neat Specimens)

Pounds per Square Inch.

Serial Number	Age When Tested				
	4 weeks	12 weeks	24 weeks	52 weeks	104 weeks
A_0	6170	7470	8030	9066	
A_{10}	5810	7543	8160	4900	3474
A_{20}	7150	7410	6920	8096	7313
A_{30}	6320	6680	7830	7057	7342
A_{40}	5670	5600	6560	5232	6179
B_0	6370	8487	5930	8347	
B_{10}	6320	10613	6970	8090	8129
B_{20}	6640	7026	7993	5259	8115
B_{30}	6360	6160	8690	6497	7523
B_{40}	6280	6520	7030	5906	5800
C_0	5560	7603	7930	7513	9245
C_{10}	5610	7373	7950	5766	8941
C_{20}	8150	5966	8190	7306	7812
C_{30}	5640	7050	8920	8083	7388
C_{40}	5450	6850	7620	5816	6913
Average of Averages.					
$A_0 - B_0 - C_0$	6033	7853	7300	8300	
$A_{10} - B_{10} - C_{10}$	5913	8509	7690	6252	6848
$A_{20} - B_{20} - C_{20}$	7310	6800	7700	6887	7747
$A_{30} - B_{30} - C_{30}$	6100	6630	8480	7212	7418
$A_{40} - B_{40} - C_{40}$	5793	6320	7070	5651	6297

For detailed results see Tables 3, 4, 5, 6, 7 and 8, Appendix B.

TABLE D

Series I

AVERAGE RESULTS OF COMPRESSIVE TESTS

(Mortar Specimens)

Pounds per Square Inch.

Serial Number	Age When Tested				
	4 weeks	12 weeks	24 weeks	52 weeks	104 weeks
A_0	3633	4980	4140	4456	3830
A_{10}	3330	3640	4350	3760	3166
A_{20}	3210	4110	3600	4067	3139
A_{30}	2033	3140	3060	2626	2489
A_{40}	1840	2790	2520	2562	2168
B_0	3430	3730	4840	3750	
B_{10}	2823	4120	3850	4202	3312
B_{20}	2803	3330	2830	3529	3349
B_{30}	2230	3160	3250	2591	2564
B_{40}	1900	2080	2410	2011	2777
C_0	3840	4830	3990	4345	5474
C_{10}	2827	3310	3850	3667	3061
C_{20}	2590	3190	2470	2607	2413
C_{30}	1580	3120	3240	2347	1819
C_{40}	1470	2433	2040	1919	2264
Average of Averages.					
$A_0 - B_0 - C_0$	3634	4510	4320	4050	4652*
$A_{10} - B_{10} - C_{10}$	2993	3690	4020	3876	3180
$A_{20} - B_{20} - C_{20}$	2868	3540	2970	3401	2967
$A_{30} - B_{30} - C_{30}$	1944	3140	3180	2521	2291
$A_{40} - B_{40} - C_{40}$	1737	2101	2320	2164	2403

*B Specimens Missing.

For detailed results see Tables 3, 9, 10, 11, 12 and 13, Appendix B.

TABLE E

Series II

AVERAGE RESULTS OF TENSION TESTS.

(Neat Specimens)

Pounds per Square Inch.

Serial Number	Age When Tested							
	24 hours	1 week	4 weeks	8 weeks	12 weeks	24 weeks	52 weeks	104 weeks
A_0	398	685	776	745	730	765	607	707
A_{25}	321	599	627	615	644	629	630	649
A_{50}	246	431	582	567	558	543	568	605
A_{75}	60	153	232	242	283	263		
$A_{87\frac{1}{2}}$		116	252		249	281	243	342
$A_{93\frac{3}{4}}$		74	160	178		227	220	95
$A_{96\frac{7}{8}}$		No			No	28		30
A_{75}*	63	250	391	441	385	313	465	
B_0	424	690	664	785	724	681	696	775
B_{25}	396	601	705	668	699	701	707	697
B_{50}	202	459	575	591	558	572	616	635
B_{75}	51	251	395	476	456	456	471	494
$B_{87\frac{1}{2}}$	No	98	217	246	251	278	291	318
$B_{93\frac{3}{4}}$	No	71	144	193	206	224	264	180
$B_{96\frac{7}{8}}$	No	No	29	No	No	42	69	57

For detailed results see Table 14, Appendix B.

TABLE F

Series II

AVERAGE RESULTS OF TENSION TESTS

(Mortar Specimens)

Pounds per Square Inch.

Serial Number	Age When Tested						
	1 week	4 weeks	8 weeks	12 weeks	24 weeks	52 weeks	104 weeks
A_0	297	409	484	474	459	400	418
A_{25}	273	383	433	412	401	405	407
A_{50}	209	291	364	380	407	344	383
A_{75}	99	188	235	278	271	282	280
$A_{87\frac{1}{2}}$	31	56		80	93	87	70
$A_{93\frac{3}{4}}$	No	No	No	No	No		
$A_{96\frac{7}{8}}$	No	No					
B_0	253	374	432	425	441	330	402
B_{25}	271	328	352	360	390	356	335
B_{50}	132	207	272	275	307	307	268
B_{75}	64	145	169	189	197	218	225
$B_{87\frac{1}{2}}$	No	62	84	100	125	145	102
$B_{93\frac{3}{4}}$	No	No	No	52	71	82	90
$B_{96\frac{7}{8}}$	No	No					

For detailed results see Table 15, Appendix B.

TABLE G

Series II

AVERAGE RESULTS OF COMPRESSIVE TESTS

(Neat Specimens)

Pounds per Square Inch.

Serial Number	Age When Tested			
	4 weeks	24 weeks	52 weeks	104 weeks
A_0	7013	7987	6368	14468
A_{25}	6477	9007	6200	8053
A_{50}	4317	5240	6590	3614
A_{75}	1280	2214	1467	1389
$A_{87\frac{1}{2}}$	1133	1992	798	
$A_{93\frac{3}{4}}$	552	815	1075	765
$A_{96\frac{7}{8}}$	No	33	22	No
B_0	6870	8010	8077	8547
B_{25}	6430	7295	7300	5470
B_{50}	4217	5586	6007	4660
B_{75}	1920	2386	2195	2408
$B_{87\frac{1}{2}}$	821	1036	1170	1223
$B_{93\frac{3}{4}}$	517	901	857	1137
$B_{96\frac{7}{8}}$	29	71	57	No

For detailed results see Tables 16, 17, 18, 19, and 20, Appendix B.

TABLE H

Series II

AVERAGE RESULTS OF COMPRESSIVE TESTS.

(Mortar Specimens)

Pounds per Square Inch.

Serial Number	Age When Tested			
	4 weeks	24 weeks	52 weeks	104 weeks
A_0	1916	2615	2334	2148
A_{25}	1988	2661	2377	2293
A_{50}	1477	2190	2137	1355
A_{75}	789	1187	937	905
$A_{87\frac{1}{2}}$	340	514	521	
$A_{93\frac{3}{4}}$	No	70		No
$A_{96\frac{7}{8}}$	No		No	
B_0	1722	2160	3703	2343
B_{25}	1980	2115	2146	1733
B_{50}	938	1195	828	
B_{75}	431	431	608	571
$B_{87\frac{1}{2}}$	308	353	1102	473
$B_{93\frac{3}{4}}$	76	202	188	314
$B_{96\frac{7}{8}}$	252		284	

For detailed results see Tables 16, 21, 22, 23, and 24, Appendix B.

APPENDIX B

This appendix contains the complete detailed results of all tests made in this investigation. The tables need no special explanation other than the following:—

Where a blank space occurs in a table, it signifies that no test was made, usually because the specimens were missing.

Where the word "No" occurs, it signifies that the specimens were tested and found to have no strength.

Series I

RESULTS OF TENSION TESTS.

(Neat Specimens)

Series Number	Specimen made 1915	24 hours	7 days	28 days	56 days	84 days	24 weeks	52 weeks	104 weeks
	-	295	743	843	769	755	830	671	770
A	12-20	343	826	861	773	728	708	773	758
	-	312	768	861	722	875	696	739	721
Avr.	-	317	779	855	758	789	744	728	750
	-	311	797	802	802	912	762	687	
B	12-20	325	812	784	783	943	635	686	
	-	282	835	878	815	784	768	670	
Avr.	-	306	815	821	801	883	722	681	
	-	400	710	758	758	711	590	642	566
C	12-20	405	612	790	727	737	647	562	600
	-	375	745	789	788	788	673	511	600
Avr.	-	393	686	779	758	745	636	572	585
	-	325	637	635	677	679	627	610	640
A_{10}	12-23	332	463	674		736	583	598	
	-	308	512	738	656	719	557	560	740
Avr.	-	322	537	682	666	711	589	589	690
	-	388	544	645	791	714	683	677	576
B_{10}	12-23	370	721	753	793	761	675	617	722
	-	340	712		790	651	676	553	740
Avr.	-	366	666	699	792	708	678	616	679
	-	320	521	765	662	686	635	412	530
C_{10}	12-22	295	648	751	724	688	593	414	450
	-	288	120		713	610	600	485	436
Avr.	-	301	630	758	700	681	608	434	472
	-	235	777	755	745	763	731	640	675
A_{20}	12-27	274	733		680	764	774	633	645
	-	220	745	675	789	792	720	765	760
Avr.	-	243	752	715	738	773	742	679	693
	-	323	716	900	750	784	776	590	650
B_{20}	12-27	364	726	902	662	796	747	554	670
	-	320	759	777	794	797	706	552	695
Avr.	-	332	733	859	735	792	743	565	672
	-	327	561		620	714	686	551	560
C_{20}	12-27	314	603	613	623	672	626	487	490
	-	277	667	652	600	724	579	498	570
Avr.	-	306	610	622	614	703	630	512	540
	-	225	622	744	872	747	726	762	670
A_{30}	12-29	303	680	820	865	777	790	675	735
	-	305	670	750	812	674		776	630
Avr.	-	278	657	771	849	732	758	738	678
	-	249	630	797	714	720	775	776	695
B_{30}	12-29	272	730	731	830	688	682	697	725
	-	255	593	762	778	700	765	717	700
Avr.	-	259	651	763	774	702	741	730	707
	-	182	579	664	784	577	620	622	580
C_{30}	12-28	177	559	544	730	627	702	580	595
	-	175	634	615	620	618	658	564	540
Avr.	-	178	591	607	711	607	660	588	572
	-	325		777	767	797	736	735	755
A_{40}	12-30	300	629	791	759	725	781	690	670
	-	305	694	693	719	793	765	743	735
Avr.	-	310	662	754	748	771	761	722	720
	-	265	583	651	735	748	633	644	668
B_{40}	12-29		482	685	775	705	743	697	720
	-		576	631	820	682	704	702	660
Avr.	-	265	547	655	777	711	693	681	689
	-	186	525	560	730	628	679	606	548
C_{40}	12-30	208	525	678	679	611	661	616	605
	-	205	485	672	711	694	603	639	544
Avr.	-	200	511	637	706	644	648	618	566
		Average of Averages.							
A - B - C		335	760	818	772	806	701	660	668*
A_{10} - B_{10} - C_{10}		330	611	713	719	700	625	546	614
A_{20} - B_{20} - C_{20}		294	692	732	702	756	705	585	628
A_{30} - B_{30} - C_{30}		238	633	714	778	780	720	685	652
A_{40} - B_{40} - C_{40}		258	573	682	758	709	701	673	658
		Average of Highest Breaks.							
A - B - C		358	802	843	759	869	757	701	685*
A_{10} - B_{10} - C_{10}		347	693	752	731	728	648	590	670
A_{20} - B_{20} - C_{20}		322	713	770	735	771	745	635	672
A_{30} - B_{30} - C_{30}		253	681	760	829	708	756	725	685
A_{40} - B_{40} - C_{40}		266	601	718	772	746	734	694	693

*B specimens missing.

Series I

RESULTS OF TENSION TESTS.

(Mortar Specimens)

Series Number	Spec's made 1915-1916	Stress in Pounds per Square Inch						
		7 days	28 days	56 days	84 days	24 weeks	52 weeks	104 weeks
	-	192	257	340	339	311	278	265
A	12-21	165	288	322	343	321	251	267
	-	200	322	314	357	299	241	250
Avr.	-	186	289	325	346	310	257	261
	-	192	332	345	389	378	360	
B	12-21	175	348	381	402	362	340	
	-	224	339	383	361	369	366	
Avr.	-	197	339	369	384	369	355	
	-	213	362	392	462	445	365	370
C	12-21	228	366	387	466	435	407	365
	-	254	395	369	485		370	310
Avr.	-	232	374	382	471	440	381	348
	-	334	462	527	524	532	404	325
A_{10}	12-31	337	443	428	476	475	411	400
	-	343	375	428	523	452	374	375
Avr.	-	338	427	461	508	486	396	367
	-	311	413	412	449	432	481	400
B_{10}	12-31	294	366	426	447	435	492	397
	-	285	496	522	487	429	466	391
Avr.	-	297	425	453	461	432	479	396
	-	320	325	351	457		380	390
C_{10}	12-30	230	304	414	511	523	504	365
	-	273	337		416	390	326	
Avr.	-	274	322	383	461	457	403	378
	-	308	417	475	389	441	400	310
A_{20}	12-31	252	404	448	404	431	397	
	-	257	396	453	458	483	408	340
Avr.	-	272	405	459	417	452	402	325
	-	284	422	430	408	448	388	340
B_{20}	12-31	299	405	400	476	421	400	330
	-	248	428	439	462	434	384	372
Avr.	-	277	418	423	448	434	391	347
	-	273	460	373	426	373	389	380
C_{20}	12-31	257	416	427	491	375	388	290
	-	268	381	455	468	411	392	336
Avr.	-	266	419	418	462	386	389	335
	-	220	381	400	484	413	370	315
A_{30}	1-1	220	367	350	426	452	362	345
	-	237	327	431	411	433	409	385
Avr.	-	225	358	393	440	433	377	348
	-	252	306	409	429	369	372	335
B_{30}	1-1	232	346	344	361	437	343	310
	-	262	350	435	451	403	383	335
Avr.	-	248	334	396	413	403	366	327
	-	248	365	346	444	417	354	310
C_{30}	1-1	260	382	476	414	407	389	
	-	267	340	402	385	460	389	360
Avr.	-	258	362	408	414	425	377	335
	-	181	356	371	381	360	385	295
A_{40}	1-1	221	339	356	364	357	298	292
	-	203	328	354	302	337	309	275
Avr.	-	201	341	360	349	351	331	287
	-	187	318	308	372	342	314	285
B_{40}	1-1	194	338	358	332	391	332	283
	-	203	318	362	403	356	345	262
Avr.	-	194	324	343	369	363	330	277
	-	181	382	342	421	357	314	285
C_{40}	1-1	218	362	375	392	387	320	335
	-	185	352	360	409	386	326	303
Avr.	-	194	365	359	407	373	323	308
		Average of Averages.						
A-B-C		205	334	359	400	373	331	305*
A_{10} - B_{10} - C_{10}		303	391	432	477	458	426	380
A_{20} - B_{20} - C_{20}		272	413	433	442	424	394	336
A_{30} - B_{30} - C_{30}		244	351	399	422	420	373	337
A_{40} - B_{40} - C_{40}		196	342	354	375	362	328	291
		Average of Highest Breaks.						
A - B - C		226	355	372	415	381	350	319*
A_{10} - B_{10} - C_{10}		325	428	467	507	497	436	397
A_{20} - B_{20} - C_{20}		293	435	456	475	447	366	364
A_{30} - B_{30} - C_{30}		255	371	447	460	450	393	360
A_{40} - B_{40} - C_{40}		208	359	369	402	379	352	305

*B Specimens missing

RESULTS OF COMPRESSION TESTS.

Series Number	Specimen made	Stress in Pounds per Square Inch									
		4 weeks Neat	4 weeks Mortar	12 weeks Neat	12 weeks Mortar	24 weeks Neat	24 weeks Mortar	52 weeks Neat	52 weeks Mortar	104 weeks Neat	104 weeks Mortar
		5480	3920	6490	5220	6930	5020	9188	3809		5467
A		7220	3360	7060	4540	11050	3380	8945	3304		2891
		5800	3620	8860	5170	6110	4020		5056		3130
Avr.		6170	3633	7470	4980	8030	4140	9066	4056		3830
		5280	3200	10380	3780	6470	4180	7984	3859		
B		6850	3390	8380	4040	4440	5500	7898	4140		
		6980	3700	6700	3380	6890	3860	9159	3252		
Avr.		6370	3430	8487	3730	5930	4840	8347	3750		
		4550	4060	6790	4720	7920	4200	6944	4350	9656	5210
C		6610	3920	6500	4680	8830	3550	8259	3772	9394	6544
		5520	3540	9520	5109	7050	4220	7337	4912	8685	4669
Avr.		5560	3840	7603	4830	7930	3990	7513	4345	9245	5474
		6590	3010	6259	2580	7780	4020	3844	3782		3092
A - 10		6430	3420	6860	4630	8640	4510	5611	3679	2833	3731
		4400	3560	9520	3720	8060	4530	5245	3820	4116	2675
Avr.		5810	3330	7543	3610	8160	4350	4900	3760	3474	3166
		6120	2700	11000	3590	7220	4460	7961	4331	7081	2143
B - 10		6450	2900	9980	5070	6520	2840	7996	3327	7817	4352
		6400	2870	10860	3640	7160	4250	8314	4948	9488	3442
Avr.		6320	2823	10613	4120	6970	3850	8090	4202	8129	3312
		5500	2660	7980	4010	7690	2580	5615	3025	8941	2738
C - 10		4660	3320	6200	2710	7780	4660	5117	4537		3793
		6660	2500	7940	3220	8380	4310	6565	3440		2653
Avr.		5610	2827	7373	3310	7950	3850	5766	3667	8941	3061
		6280	3830	6200	4300	7230	4140	8143	3812	7375	3738
A - 20		6470	2950	6960	4280	5170	3870	7258	4069	7338	2698
		8700	2850	9070	3740	8350	2780	8888	4320	7225	2981
Avr.		7150	3210	7410	4110	6920	3600	8096	4067	7313	3139
		6450	3040	4800	3330	9120	2890	6464	3166	8157	3221
B - 20		6130	2750	8210	3430	7030	2550	5166	3720	7912	3732
		7340	2620	8070	3220	7830	3040	4149	3700	8276	3095
Avr.		6640	2803	7026	3330	7993	2830	5259	3529	8115	3349
		9610		8220	3200	7180	2600	6904	2184	6622	2478
C - 20		7370		4160	3150	8720	2060	6493	2884	7255	2344
		7480	2590	5520	3220	8680	2760	8522	2740	9559	2416
Avr.		8150	2590	5966	3190	8190	2470	7306	2607	7812	2413
		6560	2500	6640	2950	8510	3540	8624	2260	6042	2217
A - 30		6200	1710	6870	3350	7840	2400	5165	3398	7519	1930
		6370	1890	6530	3110	7130	3230	7382	2220	8464	3321
Avr.		6320	2033	6680	3140	7830	3060	7057	2626	7342	2489
		6780	2340	7000	2850	7910	2510	8429	1834	7131	2871
B - 30		6180	2300	6970	3590	9620	2530	4914	2672	7953	2370
		6120	2050	4510	3050	8530	3840	6149	3268	7485	2451
Avr.		6360	2230	6160	3160	8690	3250	6497	2591	7523	2564
		5820	1550	5610	3220	9470	3770	7442	2039	6602	2201
C - 30		5360	1940	7800	3220	9450	2450	8746	2857	6940	1438
		5860	1250	7730	2930	7840	3490	8063	2144	8623	
Avr.		5640	1580	7050	3120	8920	3240	8083	2347	7388	1819
			1640	4770	2270	9950	1750	4516	2032	5767	1868
A - 40		4800	1560	5320	2970	4720	2840	4812	2975	5553	2378
		6540	2320	6700	3120	5010	2980	6369	2680	7216	2259
Avr.		5670	1840	5600	2790	6560	2520	5232	2562	6179	2168
		7070	1900	4840	1900	6960	2930	5843	1904	6204	2948
B - 40		5520	1760	7360	2090	7380	2270	4458	1870	6450	2851
		6120	2040	7370	2260	6750	2040	7418	2260	4745	2531
Avr.		6280	1900	6520	2080	7030	2410	5906	2011	5800	2777
		4710	1030	7700	2500	8710	2320	5828	2047	5287	2328
C - 40		5470	1820	6360	2930	7340	2010	5240	1428	7256	2199
		6110	1560	6490	1870	6820	2040	6380	2282	8195	
Avr.		5450	1470	6850	2433	7620	2040	5816	1919	6913	2264
Average of Averages.											
A - B - & C		6033	3634	7853	4510	7300	4320	8309	4050		4652*
A_{10} - B_{10} - C_{10}		5913	2993	8509	3690	7690	4020	6252	3876	6848	3180
A_{20} - B_{20} - C_{20}		7310	2868	6800	3540	7700	2970	6887	3401	7747	2967
A_{30} - B_{30} - C_{30}		6100	1944	6630	3140	8480	3180	7212	2521	7418	2291
A_{40} - B_{40} - C_{40}		5793	1737	6320	2101	7070	2320	5651	2164	6297	2403
Average of Highest Breaks.											
A - B - & C		6937	3890	9590	4790	8920	4910	8869	4703		6006*
A_{10}-B_{10} & C_{10}		6567	3260	9500	4570	8080	4550	6691	4435	7515	3959
A_{20}-B_{20} & C_{20}		8550	3150	8500	3660	8730	3310	7958	3641	8403	3316
A_{30}-B_{30} & C_{30}		6400	2260	7220	3390	9200	3720	8600	3174	8347	2798
A_{40}-B_{40} & C_{40}		6573	2060	7260	2770	8540	2740	6722	2506	7287	2551

*B Specimens Missing.

For detailed results see Tables 4 to 13 inclusive.

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 28 days.

(Neat Specimens)

Series Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	1.95	2.00	3.14	6.12	221	36.14	16500	17210	5260	5480
A	1-29	1.98	2.00	3.14	6.22	221	35.54	17470	22640	5560	7220
	-	2.00	2.00	3.14	6.28	231	36.79	12700	18400	4040	5800
Avr.	-							15557	19417	4950	6170
	-	2.00	2.00	3.14	6.28	231.5	36.84	14830	16550	4730	5280
B	1-29	2.00	2.00	3.14	6.28	231.5	36.84	17820	21500	5780	6850
	-	2.00	2.00	3.14	6.28	232	36.98	13090	21930	4170	6980
Avr.	-							15247	19993	4890	6370
	-	1.96	2.00	3.14	6.28	225	35.84	11100	14270	3540	4550
C	1-29	2.00	1.98	3.08	6.16	238	38.64	20740	20740	6610	6610
	-	1.96	2.02	3.20	6.27	226	36.04	15670	17670	4900	5520
Avr.	-							15837	17560	5020	5560
	-	2.02	2.06	3.33	6.73	232	34.48	11100	21940	3330	6590
A - 10	1-31	2.08	2.07	3.36	6.99	232	33.20	10000	21600	2980	6430
	-	2.00	2.03	3.23	6.46	225	34.82	9100	14200	2820	4400
Avr.	-							10063	19247	3040	5810
	-	1.96	1.99	3.11	6.10	208	34.12	12860	19000	4130	6120
B - 10	2-2	1.97	1.97	3.05	6.02	211	35.06	7000	19600	2290	6450
	-	1.96	2.00	3.14	6.16	213	34.58	17500	20070	5760	6400
Avr.	-							12453	19553	4060	6320
	-	2.05	2.05	3.30	6.76	235	34.78	15000	18150	4550	5500
C - 10	1-31	2.03	2.05	3.30	6.70	236	35.26	12400	15370	3760	4660
	-	2.07	2.05	3.30	6.83	237	34.70	13000	21970	3940	6660
Avr.	-							13467	18497	4080	5610
	-	2.02	2.11	3.49	7.05	238	33.74	17500	21890	5020	6280
A - 20	2-2	2.02	2.07	3.36	6.79	237	34.91	14500	21710	4320	6470
	-	2.02	2.03	3.23	6.52	236	36.18	23000	26060	7130	8700
Avr.	-							18333	23220	5490	7150
	-	2.01	1.97	3.05	6.12	215	35.12	13850	19680	4540	6450
B - 20	2-3	2.02	1.96	3.01	6.08	214	35.20	14570	18420	4840	6130
	-	2.03	1.96	3.01	6.12	216	35.32	20380	22100	6770	7340
Avr.	-							16267	20067	5380	6640
	-	2.00	1.97	3.05	6.10	218	35.74		29280		9610
C - 20	2-16	2.00	2.02	3.20	6.40	232	36.28	16000	23570	5010	7370
	-	2.00	2.00	3.14	6.28	229	36.50	23460	23460	7480	7480
Avr.	-							18730	25437	6250	8150
	-	1.98	2.00	3.14	6.22	228	37.68	14000	20590	4460	6560
A - 30	2-16	2.00	2.00	3.14	6.28	230	36.63	12500	19430	3980	6200
	-	2.00	1.98	3.08	6.16	218	35.41	14000	19630	4550	6370
Avr.	-							13500	19883	4330	6320
	-	2.00	2.00	3.14	6.28	225	35.84	16800	21300	5350	6780
B - 30	2-16	2.00	2.00	3.14	6.28	227	36.18	13700	19400	4370	6180
	-	2.00	2.00	3.14	6.28	225	35.84	18700	19220	5960	6120
Avr.	-							16407	19977	5230	6360
	-	2.00	2.00	3.14	6.28	227	36.18	13500	18260	4310	5820
C - 30	2-17	2.01	1.98	3.08	6.16	221	35.90	14020	16500	4560	5360
	-	2.02	2.00	3.14	6.28	226	36.00	17620	18400	5620	5860
Avr	-							15047	17720	4830	5640
	-	2.02	1.97	3.05	6.16	220	35.72				
A - 40	2-19	2.00	1.97	3.05	6.10	220	36.08	12940	14630	4240	4800
	-	2.00	2.02	3.20	6.40	229	35.81	20920	20920	6540	6540
Avr.	-							16930	17775	5390	5670
	-	2.01	1.99	3.11	6.25	219	35.05	21050	22000	6770	7070
B - 40	2-19	2.02	2.02	3.20	6.47	229	35.40	17640	17640	5520	5520
	-	2.00	2.02	3.20	6.40	227	35.50	19530	19530	6120	6120
Avr.	-							19407	19723	6130	6280
	-	2.03	2.02	3.20	6.50	232	35.70	15060	15060	4710	4710
C - 40	2-23	2.05	2.01	3.17	6.28	231	36.79	16900	17330	5330	5470
	-	2.02	1.99	3.11	6.28	221	35.20	17300	18990	5570	6110*
Avr.	-							16420	17130	5200	5450
Average of Averages.											
A - B - C										4953	6033
$A_{10} - B_{10} - C_{10}$										3727	5913
$A_{20} - B_{20} - C_{20}$										5700	7310
$A_{30} - B_{30} - C_{30}$										4797	6100
$A_{40} - B_{40} - C_{40}$										5573	5793
Average of Highest Breaks.											
A - B - C										5983	6937
$A_{10} - B_{10} - C_{10}$										4547	6567
$A_{20} - B_{20} - C_{20}$										7127	8550
$A_{30} - B_{30} - C_{30}$										5343	6400
$A_{40} - B_{40} - C_{40}$										6293	6573

*Broken on end.

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 12 weeks.

(Neat Specimens)

Series Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.00	1.98	3.08	6.16	238	38.62	17200	19820	5580	6490
A	1-29	2.01	2.00	3.14	6.31	238	37.7	17250	22150	5500	7060
	-	2.04	1.98	3.08	6.29	237	37.67	27240	27240	8860	8860
Avr.	-							20563	23070	6650	7470
	-	2.00	1.97	3.05	6.10	234	38.38	31620	31620	10380	10380
B	1-29	2.02	1.98	3.08	6.23	237	38.04	20080	25800	10530	8380
	-	2.00	1.97	3.05	6.10	236	38.7	12100	20410	3970	6700
Avr.	-							21267	25943	8293	8487
	-	2.00	1.98	3.08	6.16	227	36.88	12810	20910	4160	6790
C	1-29	1.98	1.96	3.01	5.96	224	37.61	13110	19540	4360	6500
	-	2.00	1.96	3.01	6.02	229	38.02	17870	28610	5940	9520
Avr.	-							14597	23020	4820	7603
	-	2.04	2.02	3.20	6.53	234	35.85	15400	20000	4820	6250
A_{10}	1-31	2.05	2.04	3.27	6.70	235	35.08	11300	22400	3460	6860
	-	2.00	2.00	3.14	6.28	219	34.88	12100	29829	3850	9520
Avr.	-							12933	24073	4040	7543
	-	1.97	1.98	3.08	6.07	215	35.42	17460	33880	5670	11000
B_{10}	2-2	1.98	1.96	3.01	5.96	215	36.08	23870	30010	7940	9980
	-	2.00	1.98	3.08	6.16	215	34.9	20010	33500	6500	10860
Avr.	-							20447	32463	6700	10673
	-	2.06	2.04	3.27	6.74	238	35.3	16710	26120	5220	7980
C_{10}	1-31	2.06	2.04	3.27	6.74	239	35.47	6470	20250	1980	6200
	-	2.04	2.02	3.20	6.53	239	36.61	10640	25410	3330	7940
Avr.	-							11273	23927	3510	7373
	-	2.06	2.03	3.23	6.66	236	35.43	15400	20000	4780	6200
A_{20}	2-2	2.05	2.03	3.23	6.63	236	35.6	11300	22440	3500	6960
	-	2.06	2.04	3.27	6.74	238	35.3	12100	29820	3710	9070
Avr.	-							12933	24086	4000	7410
	-	2.04	2.02	3.20	6.53	230	35.24	7680	15350	2400	4800
B_{20}	2-3	2.03	1.99	3.11	6.32	216	34.17	19030	25540	6130	8210
	-	2.04	1.98	3.08	6.29	217	34.5	15260	24830	4950	8070
Avr.	-							13990	21907	4490	7026
	-	2.01	1.98	3.08	6.19	222	35.88	14360	25340	4670	8220
C_{20}	2-16	2.00	2.00	3.14	6.28	221	36.23	9800	13060	2960	4160
	-	1.99	1.99	3.11	6.20	219	35.34	14850	17140	4780	5520
Avr.	-							13003	18513	4140	5966
	-	2.00	1.97	3.05	6.10	220	36.08	9160	20240	3000	6640
A_{30}	2-16	2.00	1.98	3.08	6.16	219	35.57	10770	21150	3500	6870
	-	2.02	2.00	3.14	6.34	234	36.91	8430	20490	2680	6530
Avr.	-							9453	20620	3060	6680
	-	2.02	2.00	3.14	6.34	227	35.8	16460	21980	5240	7000
B_{30}	2-16	2.04	2.01	3.17	6.47	228	35.23	15970	22080	5040	6970
	-	2.04	2.02	3.20	6.53	229	35.08	12100	14420	3780	4510
Avr.	-							14843	19493	4690	6160
	-	2.01	1.96	3.01	6.05	219	36.21	18110	18110	5610	5610
C_{30}	2-17	2.01	1.97	3.05	6.13	218	35.57	13550	23770	4440	7800
	-	2.09	2.02	3.20	6.69	237	35.43	24710	24710	7730	7730
Avr.	-							18790	22196	5930	7050
	-	2.00	2.03	3.23	6.46	232	35.88	8050	15370	2490	4770
A_{40}	2-19	2.01	2.02	3.20	6.43	231	35.92	14630	17000	4580	5320
	-	2.01	2.00	3.14	6.31	227	35.98	21000	21000	6700	6700
Avr.	-							14550	17790	4590	5600
	-	2.03	2.00	3.14	6.37	227	35.66	13430	15190	4280	4840
B_{40}	2-19	2.03	2.02	3.20	6.50	228	35.08	23560	23560	7360	7360
	-	2.00	2.00	3.14	6.28	225	35.84	22080	23140	7030	7370
Avr.	-							19690	20630	6220	6520
	-	2.03	1.99	3.11	6.32	223	35.28	23950	23950	7700	7700
C_{40}	2-23	2.05	2.03	3.22	6.60	233	35.3	18870	20490	5870	6360
	-	2.05	2.02	3.20	6.56	233	35.5	20750	20750	6490	6490
Avr.	-							21190	21730	6690	6850
Average of Averages.											
A - B - C										6587	7853
A_{10} - B_{10} - C_{10}										4750	8509
A_{20} - B_{20} - C_{20}										4210	6800
A_{30} - B_{30} - C_{30}										4560	6630
A_{40} - B_{40} - C_{40}										5830	6320
Average of Highest Breaks.											
A - B - C										8390	9590
A_{10} - B_{10} - C_{10}										5990	9500
A_{20} - B_{20} - C_{20}										5230	8500
A_{30} - B_{30} - C_{30}										5490	7220
A_{40} - B_{40} - C_{40}										7250	7260

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 24 weeks.

(Neat Specimens)

Series Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.04	2.02	3.20	6.53	237	36.30	17740	22190	5550	6930
A	1-29	2.04	2.00	3.14	6.41	239	37.30	20220	34740	6450	11050
	-	2.03	2.01	3.17	6.44	239	37.12	18660	19360	5880	6110
Avr.	-							18873	25430	5960	8030
	-	2.03	2.02	3.20	6.50	238	36.64	15490	20690	4840	6470
B	1-29	2.02	2.02	3.20	6.47	234	36.18	8720	14190	2720	4440
	-	2.04	2.02	3.20	6.53	237	36.30	16820	22020	5260	6890
Avr.	-							13677	18967	4270	5930
	-	2.08	2.02	3.20	6.66	237	35.59	19830	25320	6200	7920
C	1-29	2.08	2.02	3.20	6.66	226	33.92	25150	28240	7860	8830
	-	2.02	2.04	3.27	6.61	238	36.01	23050	23050	7050	7050
Avr.	-							22677	25537	7040	7930
	-	2.08	2.02	3.20	6.66	236	35.45	11450	24870	3580	7780
A_{10}	1-31	2.05	2.04	3.27	6.70	236	35.25	10110	28230	3090	8640
	-	2.01	2.01	3.17	6.37	220	34.52	23840	25570	7530	8060
Avr.	-							15133	26223	4730	8160
	-	1.98	1.98	3.08	6.10	212	34.78	12560	22210	4080	7220
B_{10}	2-2	2.01	2.00	3.14	6.31	215	34.08	17200	20480	5480	6520
	-	2.02	1.97	3.05	6.16	216	35.07	15030	21810	4930	7160
Avr.	-							14930	21500	4830	6970
	-	2.06	2.04	3.27	6.78	237	34.97	25080	25140	7680	7690
C_{10}	1-31	2.06	2.02	3.20	6.59	240	36.42	18530	24910	5800	7780
	-	2.06	2.03	3.23	6.65	240	36.10	19000	27030	5890	8380
Avr.	-							20870	25693	6460	7950
	-	2.10	2.01	3.17	6.66	238	35.77	19330	22890	6100	7230
A_{20}	2-2	2.00	2.02	3.20	6.69	240	35.90	10650	16510	3330	5170
	-	2.06	2.02	3.20	6.59	238	36.14	15590	26710	4870	8350
Avr.	-							15190	22031	4770	6920
	-	2.05	2.04	3.27	6.70	232	34.63	19920	29810	6100	9120*
B_{20}	2-3	2.06	2.02	3.20	6.59	230	34.92	22470	22470	7030	7030*
	-	2.03	2.00	3.14	6.37	217	34.08	11340	24606	3620	7830*
Avr.	-							17910	25627	5580	7993
	-	2.01	2.00	3.14	6.31	221	35.05	12620	22530	4020	7180
C_{20}	2-16	2.00	2.04	3.27	6.54	234	35.77	16940	28430	5180	8720
	-	2.01	1.98	3.08	6.19	219	35.40	22490	26740	7300	8680
Avr.	-							17350	25900	5500	8190
	-	2.00	2.00	3.14	6.28	219	34.88	23000	26690	7330	8510
A_{30}	2-16	2.00	1.99	3.11	6.22	220	35.35	20890	24670	6720	7840
	-	2.04	2.02	3.20	6.53	232	35.51	5130	22800	1600	7130
Avr.	-							16340	24720	5220	7830
	-	2.03	2.03	3.23	6.56	227	34.61	23840	25530	7380	7910
B_{30}	2-16	2.02	2.02	3.20	6.47	228	35.25	30770	30770	9620	9620
	-	2.01	1.99	3.11	6.25	217	34.72	22080	26510	7110	8530
Avr.	-							25563	27603	8040	8690
	-	2.00	2.04	3.27	6.54	232	35.48	30980	30980	9470	9470
C_{30}	2-17	2.00	1.97	3.05	6.10	217	35.59	30870	30870	9450	9450
	-	2.00	1.98	3.08	6.16	220	35.72	21800	24130	7080	7840
Avr.	-							27883	28660	8670	8920
	-	2.04	2.02	3.20	6.53	232	35.53	31840	31840	9950	9950
A_{40}	2-19	2.08	1.98	3.08	6.25	217	34.74		14520		4720
	-	2.04	2.05	3.30	6.73	232	34.50	7580	16520	2290	5010
Avr.	-							19710	20960	6120	6560
	-	2.02	1.99	3.11	6.28	219	34.88	19450	21610	6260	6960
B_{40}	2-19	2.01	1.99	3.11	6.25	217	34.74	20340	22970	6530	7380
	-	2.02	2.00	3.14	6.35	217	34.20	15320	21180	4880	6750
Avr.	-							18370	21920	5890	7030
	-	2.04	2.04	3.27	6.67	235	35.23	28450	28450	8710	8710
C_{40}	2-23	2.01	2.00	3.14	6.32	223	35.30	23040	23040	7340	7340
	-	2.04	2.00	3.14	6.41	224	34.94	21720	21720	6820	6820
Avr.	-							24403	24403	7620	7620
		Average of Averages.									
A - B - C										5760	7300
A_{10} - B_{10} - C_{10}										5340	7690
A_{20} - B_{20} - C_{20}										5280	7700
A_{30} - B_{30} - C_{30}										7310	8480
A_{40} - B_{40} - C_{40}										6540	7070
		Average of Highest Breaks.									
A - B - C										6520	8920
A_{10} - B_{10} - C_{10}										6900	8080
A_{20} - B_{20} - C_{20}										6810	8730
A_{30} - B_{30} - C_{30}										8810	9200
A_{40} - B_{40} - C_{40}										8400	8540

*Due $^{7}/_{20}$ - '16; Tested $^{7}/_{19}$ - '16.

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 52 weeks.

(Neat Specimens)

Serial Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.04	1.98	3.08	6.28	230	36.62	16800	28300	5454	9188
A	1-29	1.99	1.98	3.08	6.15	226	36.86	17500	27550	5682	8845
	-										
Avr.	-							17150	27925	5568	9066
	-	2.00	2.00	3.14	6.28	239	38.05	21000	25070	6688	7984
B	1-29	2.00	2.00	3.14	6.28	238	37.89	16000	24800	5095	7898
	-	2.03	2.00	3.14	6.37	237	37.25	20000	28760	6369	9159
Avr.	-							19000	26210	6050	8347
	-	2.00	2.00	3.14	6.28	239	38.05	19800	21850	6306	6944
C	1-29	2.00	1.98	3.08	6.15	229	37.17	20800	25440	6753	8259
	-	2.00	2.00	3.14	6.28	240	38.21	11500	23040	3667	7337
Avr.	-							17333	23443	5574	7513
	-	2.00	2.00	3.14	6.28	236	37.58	5200	12070	1656	3844
A_{10}	1-31	2.01	2.00	3.14	6.31	237	37.56	7000	17620	2229	5611
	-	2.00	2.00	3.14	6.28	235	37.42	7100	16470	2261	5245
Avr.	-							6433	15386	2049	4900
	-	2.00	2.00	3.14	6.28	230	36.62	13020	25000	4146	7961
B_{10}	2-2	2.00	1.96	3.02	6.04	216	35.76	10500	24150	3476	7996
	-	2.00	1.97	3.05	6.10	217	35.57	12500	25360	4098	8314
Avr.	-							12340	24837	3907	8090
	-	2.05	2.01	3.17	6.50	240	36.92	17000	17800	5362	5615
C_{10}	1-31	2.05	2.05	3.30	6.77	241	35.59	13400	16885	4060	5117
	-	2.03	2.04	3.27	6.64	243	36.60	6400	21470	1954	6565
Avr.	-							12133	18718	3792	5766
	-	2.07	2.00	3.14	6.50	239	36.77	17500	25570	5573	8143
A_{20}	2-2	2.06	2.01	3.17	6.53	238	36.44	11000	23010	3470	7258
	-	2.00	2.00	3.14	6.28	221	35.19	16420	27910	5229	8888
Avr.	-							14973	25496	4757	8096
	-	2.06	2.04	3.27	6.74	233	34.57	13000	21150	3975	6464
B_{20}	2-3	2.04	2.03	3.24	6.61	232	35.09	11000	16740	3395	5166
	-	2.00	2.00	3.14	6.28	220	35.03	9200	13030	2929	4149
Avr.	-							11067	16973	3433	5259
	-	1.98	2.00	3.14	6.22	220	35.38	17200	21680	5477	6904
C_{20}	2-16	2.00	2.00	3.14	6.28	235	37.40	13800	20390	3494	6493
	-	2.00	2.00	3.14	6.28	200	31.80	26760	26760	8522	8522
Avr.	-							19253	22943	5831	7306
	-	2.04	2.00	3.14	6.41	235	36.65	17000	27090	5414	8624
A_{30}	2-16	2.04	2.00	3.14	6.41	234	36.48	5200	16220	1656	5665
	-	2.00	2.00	3.14	6.28	232	36.95	15070	23180	4799	7382
Avr.	-							12423	22163	3956	7057
	-	2.00	2.00	3.14	6.28	229	36.48	22000	26470	7006	8429
B_{30}	2-16	2.00	2.00	3.14	6.28	232	36.96	9500	15440	3025	4914
	-	2.00	2.00	3.14	6.28	219	34.90	17100	19310	5445	6149
Avr.	-							16200	20406	5159	6497
	-	2.00	2.00	3.14	6.28	224	35.64	23370	23370	7442	7442
C_{30}	2-17	2.05	2.04	3.27	6.70	240	35.80	27500	28600	8409	8746
	-	2.04	2.00	3.14	6.41	227	35.40	19200	25320	6114	8063
Avr.	-							20023	25763	7322	8083
	-	2.00	2.00	3.14	6.28	217	34.59	10000	14180	3184	4516
A_{40}	2-19	2.00	2.00	3.14	6.28	207	32.97	12000	15110	3821	4812
	-	2.00	2.00	3.14	6.28	232	36.95	18000	20000	5732	6369
Avr.	-							13333	16430	4245	5232
	-	2.01	1.98	3.08	6.19	222	35.87	18000	18000	5843	5843
B_{40}	2-19	2.00	2.00	3.14	6.28	220	35.00	12000	14000	3821	4458
	-	2.00	1.99	3.11	6.22	219	35.20	23070	23070	7418	7418
Avr.	-							17690	18357	5694	5906
	-	2.00	2.00	3.14	6.27	225	35.90	17000	18310	5412	5828
C_{40}	2-23	2.00	1.99	3.11	6.22	224	36.00	10100	16310	3246	5240
	-	2.00	1.98	3.08	6.16	224	36.36	15500	19670	5030	6380
Avr.	-							14200	18097	4563	5816
		Averages of Averages.									
A - B & C										5731	8309
A_{10} - B_{10} & C_{10}										3249	6252
A_{20} - B_{20} & C_{20}										4674	6887
A_{30} - B_{30} & C_{30}										5479	7212
A_{40} - B_{40} & C_{40}										4834	5650
		Average of Highest Breaks.									
A - B & C										6374	8869
A_{10} - B_{10} & C_{10}										3923	6691
A_{20} - B_{20} & C_{20}										6023	7958
A_{30} - B_{30} & C_{30}										6943	8600
A_{40} - B_{40} & C_{40}										6187	6722

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 104 weeks.
(Neat Specimens)

Serial Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
A	1-29										
A - 10	1-31	2.06	2.03	3.24	6.67	236	35.38	8080	9180	2494	2833
	-	2.07	1.99	3.11	6.44	229	35.56	8020	12800	2579	4116
Avr.								8050	10990	2536	3474
	-	2.10	2.02	3.20	6.72	241	35.86	18130	23600	5666	7375
A - 20	2-2	2.09	2.02	3.20	6.69	241	36.02	16130	23480	5041	7338
	-	2.08	2.02	3.20	6.66	240	36.04	16140	23120	5044	7225
Avr.								16800	23400	5250	7313
	-	2.00	1.98	3.08	6.16	221	35.88	10430	18610	3386	6042
A - 30	2-16	2.00	2.00	3.14	6.28	236	37.58	15270	23610	4863	7519
	-	2.04	1.94	2.95	6.02	221	36.71	11490	24970	3895	8464
Avr.								12397	22397	4048	7342
	-	2.00	1.97	3.05	6.10	223	36.56	13010	17590	4266	5767
A - 40	2-19	2.00	2.02	3.20	6.40	227	35.47	11290	17770	3528	5553
	-	2.00	2.02	3.20	6.40	235	36.72	13560	23090	4238	7216
Avr.								12620	19483	4011	6179
B	1-29										
Avr.											
	-	2.02	2.02	3.20	6.46	230	35.60	10950	22660	3422	7081
B - 10	2-2	2.02	2.01	3.17	6.40	230	35.94	10600	24780	3344	7817
	-	2.00	1.97	3.05	6.10	215	35.24	15740	28940	5161	9488
Avr.								12430	25460	3976	8129
	-	2.10	2.03	3.24	6.80	234	34.41	19970	26430	6164	8157
B - 20	2-3	2.07	1.98	3.08	6.38	221	34.64	12930	24370	4198	7912
	-	2.05	1.98	3.08	6.31	221	35.02	15150	25490	4919	8276
Avr.								16017	25430	5094	8115
	-	2.02	2.02	3.20	6.46	230	35.60	12740	22820	3981	7131
B - 30	2-16	2.03	2.02	3.20	6.50	231	35.54	15160	25450	4738	7953
	-	2.00	1.97	3.05	6.10	219	35.90	13880	22830	4551	7485
Avr.								13927	23700	4423	7523
	-	2.06	2.03	3.24	6.67	234	35.08	13820	20100	4265	6204
B - 40	2-19	2.04	1.99	3.11	6.34	219	34.54	15770	20060	5071	6450
	-	2.03	2.00	3.14	6.37	218	34.22	5830	14900	1857	4745
Avr.								11807	18353	3731	5800
	-	2.00	2.01	3.17	6.34	240	37.85	18500	30610	5836	9656
C	1-29	2.00	1.96	3.02	6.04	229	37.91	22170	28370	7341	9394
	-	2.02	1.96	3.02	6.10	229	37.54	21620	26230	7159	8685
Avr.								20763	28403	6779	9245
	-	2.06	2.03	3.24	6.67	240	35.98	9280	28970	2865	8941
C - 10	1-31										
Avr.	-										
	-							9280	28970	2865	8941
	-	2.00	1.96	3.02	6.04	221	36.59	19240	20000	6371	6622
C - 20	2-16	2.06	2.00	3.14	6.47	234	36.17	15600	22780	4968	7255
	-	2.08	2.02	3.20	6.66	235	35.29	24800	30590	7750	9559
Avr.								19880	24457	6363	7812
	-	2.00	2.00	3.14	6.28	232	36.94	16620	20730	5293	6602
C - 30	2-17	2.06	2.01	3.17	6.53	237	36.29	16600	22000	5237	6940
	-	2.04	1.97	3.05	6.22	229	36.82	17000	26300	5574	8623
Avr.								16740	23010	5368	7388
	-	2.05	2.04	3.27	6.70	236	35.22	9050	17290	2768	5287
C - 40	2-23	2.03	1.98	3.08	6.25	226	36.16	14840	22350	4818	7256
	-	2.00	1.98	3.08	6.16	226	36.69	20200	25240	6558	8195
Avr.	-							14697	21627	4715	6913
A - B - C	Average of Averages.										
$A_{10} - B_{10} - C_{10}$											6848
$A_{20} - B_{20} - C_{20}$											7747
$A_{30} - B_{30} - C_{30}$											7418
$A_{40} - B_{40} - C_{40}$											6297

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 28 days.

(Mortar Specimens)

Series Number	Spec's made 1916 Date	Dimensions				Weight		Load		Stress	
		Height inches	Diam. inches	Area in Sq. in.	Vol. in Cu. in.	Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.05	2.06	3.33	6.83	258	37.77	13060	13060	3920	3920
A	2-23	2.03	2.00	3.14	6.37	239	37.52	10560	10560	3360	3360
	-	2.02	1.99	3.11	6.28	244	38.86	11240	11240	3620	3620
Avr.	-							11620	11620	3633	3633
	-	2.06	2.02	3.20	6.59	252	38.21	10240	10240	3200	3200
B	2-23	2.10	2.02	3.20	6.72	256	38.10	10830	10830	3390	3390
	-	2.08	2.03	3.23	6.73	257	38.2	11970	11970	3700	3700
Avr.	-							11013	11013	3430	3430
	-	2.10	2.02	3.20	6.72	258	38.4	12990	12990	4060	4060
C	2-26	2.10	2.04	3.27	6.87	260	37.81	12540	12540	3920	3920
	-	2.09	2.01	3.17	6.62	254	38.38	11200	11200	3540	3540
Avr.	-							12243	12243	3840	3840
	-	2.08	2.00	3.14	6.53	240	36.76	9450	9450	3010	3010
A_{10}	2-26	2.10	2.02	3.20	6.72	256	38.1	10960	10960	3420	3420
	-	2.09	2.02	3.20	6.68	254	38.04	11400	11400	3560	3560
Avr.	-							10603	10603	3330	3330
	-	2.05	2.00	3.14	6.44	235	36.5	7000	8500	2220	2700
B_{10}	2-26	2.04	1.99	3.11	6.35	233	36.7	9020	9020	2900	2900
	-	2.05	2.04	3.27	6.70	247	36.88	9400	9400	2870	2870
Avr.	-							8473	8773	2663	2823
	-	2.10	2.02	3.20	6.72	251	37.38	8520	8520	2660	2660
C_{10}	2-26	2.07	1.98	3.08	6.38	239	37.47	10210	10210	3320	3320
	-	2.06	1.98	3.08	6.35	251	39.52	7710	7710	2500	2500
Avr.	-							8813	8813	2827	2827
	-	2.05	2.00	3.14	6.44	246	38.2	11000	12010	3500	3830
A_{20}	2-28	2.04	1.97	3.05	6.23	242	38.86	9000	9000	2950	2950
	-	2.05	1.98	3.08	6.32	243	38.46	8690	8690	2850	2850
Avr.	-							9563	9900	3100	3210
	-	2.10	2.01	3.17	6.65	252	37.9	9650	9650	3040	3040
B_{20}	2-28	2.07	2.03	3.28	6.69	252	37.66	8900	8900	2750	2750
	-	2.07	1.97	3.05	6.32	237	37.5	8000	8000	2620	2620
Avr.	-							8850	8850	2803	2803
	-	2.06	2.03	3.23	6.66	249	37.39				
C_{20}	2-28	2.06	1.98	3.08	6.35	241	37.98	5740	5740	1860	1860*
	-	2.05	2.03	3.23	6.62	236	35.64	5720	8380	1770	2590
Avr.	-							5720	8380	1770	2590
	-	2.09	1.98	3.08	6.44	236	36.62	7710	7710	2500	2500
A_{30}	3-1	2.09	2.03	3.23	6.75	254	37.66	5520	5520	1710	1710
	-	2.10	2.10	3.46	7.27	243	33.42	6550	6550	1890	1890
Avr.	-							6593	6593	2033	2033
	-	2.10	1.98	3.08	6.47	241	37.28	7230	7230	2340	2340
B_{30}	3-1	2.10	2.00	3.14	6.60	251	38.04	7220	7220	2300	2300
	-	2.12	2.02	3.20	6.78	254	37.48	6560	6560	2050	2050
Avr.	-							7003	7003	2230	2230
	-	2.10	2.02	3.20	6.72	254	37.78	4950	4950	1550	1550
C_{30}	3-1	2.08	1.99	3.11	6.47	237	36.62	6030	6030	1940	1940
	-	2.12	2.00	3.14	6.65	254	38.18	3930	3930	1250	1250
Avr.	-							4970	4970	1580	1580
	-	2.08	1.99	3.11	6.47	240	37.10	5090	5090	1640	1640
A_{40}	3-3	2.06	1.97	3.05	6.29	236	37.56	4760	4760	1560	1560
	-	2.12	2.02	3.20	6.78	252	37.16	7420	7420	2320	2320
Avr.	-							5760	5760	1840	1840
	-	2.06	2.02	3.20	6.59	251	38.1	6100	6100	1900	1900
B_{40}	3-3	2.04	2.00	3.14	6.41	237	36.98	5520	5520	1760	1760
	-	2.06	2.02	3.20	6.59	248	37.62	6550	6550	2040	2040
Avr.	-							6057	6057	1900	1900
	-	2.08	2.02	3.20	6.66	247	37.1	3300	3300	1030	1030
C_{40}	3-3	2.08	2.03	3.23	6.73	250	37.16	5870	5870	1820	1820
	-	2.05	1.98	3.08	6.32	234	37.02	4820	4820	1560	1560
Avr.	-							4663	4663	1470	1470
Average of Averages.											
A - B - C										3634	3634
A_{10} - B_{10} - C_{10}										2940	2993
A_{20} - B_{20} - C_{20}										2558	2868
A_{30} - B_{30} - C_{30}										1944	1944
A_{40} - B_{40} - C_{40}										1737	1737
Average of Highest Breaks.											
A - B - C										3890	3890
A_{10} - B_{10} - C_{10}										3260	3260
A_{20} - B_{20} - C_{20}										2770	3150
A_{30} - B_{30} - C_{30}										2260	2260
A_{40} - B_{40} - C_{40}										2060	2060

*Omit.

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 12 weeks.

(Mortar Specimens)

Series Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.10	2.05	3.30	6.93	257	37.10	17220	17220	5220	5220
A	2-23	2.08	1.95	2.98	6.20	237	38.23	13510	13510	4540	4540
	-	2.11	2.02	3.20	6.75	256	37.92	16540	16540	5170	5170
Avr.	-							15757	15757	4980	4980
	-	2.07	2.02	3.20	6.62	254	38.37	12080	12080	3780	3780
B	2-23	2.10	2.01	3.17	6.66	251	37.70	12810	12810	4040	4040
	-	2.10	2.04	3.27	6.87	258	37.56	10600	10600	3380	3380
Avr.	-							11830	11830	3730	3730
	-	2.08	1.99	3.11	6.47	247	38.19	14690	14690	4720	4720
C	2-26	2.10	2.02	3.20	6.72	255	37.94	14980	14980	4680	4680
	-	2.13	2.00	3.14	6.68	262	39.23	16000	16000	5100	5100
Avr.	-							15223	15223	4830	4830
	-	2.02	2.01	3.17	6.41	240	37.44	8190	8190	2580	2580
A_{10}	2-26	2.03	2.00	3.14	6.38	239	37.46	14560	14560	4630	4630
	-	2.04	1.98	3.08	6.28	235	37.42	11460	11460	3720	3720
Avr.	-							11400	11400	3640	3640
	-	2.04	2.04	3.27	6.67	247	37.06	11730	11730	3590	3590
B_{10}	2-26	2.02	1.97	3.05	6.16	236	38.30	15420	15420	5070	5070
	-	2.03	2.04	3.27	6.64	247	37.23	12070	12070	3690	3640
Avr.	-							13073	13073	4120	4120
	-	2.11	2.02	3.20	6.75	254	37.83	12810	12810	4010	4010
C_{10}	2-26	2.10	2.02	3.20	6.72	253	37.64	8690	8690	2710	2710
	-	2.10	2.02	3.20	6.72	252	37.51	10310	10310	3220	3220
Avr.	-							10603	10603	3310	3310
	-	2.10	2.02	3.20	6.72	252	37.51	13750	13750	4300	4300
A_{20}	2-28	2.09	1.99	3.11	6.50	242	37.22	13300	13300	4280	4280
	-	2.08	1.99	3.11	6.47	242	37.41	11640	11640	3740	3740
Avr.	-							12897	12897	4110	4110
	-	2.10	2.03	3.23	6.78	258	38.08	10740	10740	3330	3330
B_{20}	2-28	2.07	1.98	3.08	6.38	237	37.16	10560	10560	3430	3430
	-	2.10	2.02	3.20	6.72	253	37.64	10310	10310	3220	3220
Avr.	-							10537	10537	3330	3330
	-	2.05	2.00	3.14	6.44	238	36.96	10030	10030	3200	3200
C_{20}	2-28	2.10	2.02	3.20	6.72	253	37.64	10080	10080	3150	3150
	-	2.06	1.98	3.08	6.35	240	37.80	9920	9920	3220	3220
Avr.	-							10010	10010	3190	3190
	-	2.08	2.00	3.14	6.53	240	36.77	9270	9270	2950	2950
A_{30}	3-1	2.12	2.04	3.27	6.93	255	36.82	10930	10930	3350	3350
	-	2.04	2.00	3.14	6.41	256	39.94	9780	9780	3110	3110
Avr.	-							9993	9993	3140	3140
	-	2.10	2.00	3.14	6.60	252	38.17	8960	8960	2850	2850
B_{30}	3-1	2.08	1.99	3.11	6.47	241	37.26	11180	11180	3590	3590
	-	2.08	1.99	3.11	6.47	240	37.08	9490	9490	3050	3050
Avr.	-							9877	9877	3160	3160
	-	2.08	1.98	3.08	6.41	236	36.82	9920	9920	3220	3220
C_{30}	3-1	2.07	1.98	3.08	6.38	239	37.46	9930	9930	3220	3220
	-	2.10	2.02	3.20	6.72	254	37.79	9370	9370	2930	2930
Avr.	-							9740	9740	3120	3120
	-	2.10	1.98	3.08	6.47	237	36.64	6990	6990	2270	2270
A_{40}	3-3	2.10	2.02	3.20	6.72	249	37.04	9500	9500	2970	2970
	-	2.10	2.00	3.14	6.60	248	37.58	9820	9820	3120	3120
Avr.	-							8770	8770	2790	2790
	-	2.10	2.00	3.14	6.60	240	36.38	5960	5960	1900	1900
B_{40}	3-3	2.08	2.00	3.14	6.53	243	37.23	6560	6560	2090	2090
	-	2.08	2.00	3.14	6.53	241	36.92	7110	7110	2260	2260
Avr.	-							6543	6543	2080	2080
	-	2.10	2.00	3.14	6.60	237	35.92	7870	7870	2500	2500
C_{40}	3-3	2.05	1.98	3.08	6.32	236	37.39	9040	9040	2930	2930
	-	2.05	1.98	3.08	6.32	232	36.70	5770	5770	1870	1870*
Avr.	-							7560	7560	2433	2433
Average of Averages.											
A - B - C										4510	4510
A_{10} - B_{10} - C_{10}										3690	3690
A_{20} - B_{20} - C_{20}										3540	3540
A_{30} - B_{30} - C_{30}										3140	3140
A_{40} - B_{40} - C_{40}										2101	2101
Average of Highest Breaks.											
A - B - C										4790	4790
A_{10} - B_{10} - C_{10}										4570	4570
A_{20} - B_{20} - C_{20}										3660	3660
A_{30} - B_{30} - C_{30}										3390	3390
A_{40} - B_{40} - C_{40}										2770	2770

*Chip off of end.

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 24 weeks.

(Mortar Specimens)

Serial Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	lb./sq. in. Ult.
	-	2.11	2.01	3.17	6.69	258	38.57	13730	15890	4330	5020
A	2-23	2.08	2.04	3.27	6.80	257	37.83	10290	11060	3150	3380
	-	2.12	2.01	3.17	6.72	259	38.52		12710		4020
Avr.	-							12010	13220	3740	4140
	-	2.12	2.03	3.23	6.85	254	37.08	13480	13480	4180	4180
B	2-23	2.10	2.04	3.27	6.87	252	36.66		17280		5500†
	-	2.08	1.97	3.05	6.35	249	39.22	11280	11770	3700	3860*
Avr.	-							13480	15380	4180	4840
	-	2.11	2.00	3.14	6.63	247	37.24	13180	13180	4200	4200
C	2-26	2.09	2.00	3.14	6.57	244	37.16	11150	11150	3550	3550
	-	2.11	2.02	3.20	6.75	256	37.94		13490		4220
Avr.	-							12165	12607	3870	3990
	-	2.06	1.98	3.08	6.35	236	37.20	12370	12370	4020	4020
A_{10}	2-26	2.12	2.02	3.20	6.78	255	37.60	14410	14410	4510	4510
	-	2.12	2.03	3.23	6.85	256	37.39	14630	14630	4530	4530
Avr.	-							13803	13803	4350	4350
	-	2.10	2.00	3.14	6.60	245	37.10	14000	14000	4460	4460
B_{10}	2-26	2.07	2.05	3.30	6.83	249	36.48	9390	9390	2840	2840
	-	2.06	2.05	3.30	6.80	246	36.18	14010	14010	4250	4250
Avr.	-							12467	12467	3850	3850
	-	2.10	2.03	3.23	6.78	252	37.14	8340	8340	2580	2580
C_{10}	2-26	2.11	2.04	3.27	6.90	252	36.52	15230	15230	4660	4660†
	-	2.10	1.99	3.11	6.54	241	36.87	13380	13380	4310	4310§
Avr.	-							12317	12317	3850	3850
	-	2.11	2.05	3.30	6.96	257	36.94	13660	13660	4140	4140
A_{20}	2-28	2.07	2.00	3.14	6.50	242	37.24	12160	12160	3870	3870
	-	2.10	2.00	3.14	6.60	242	36.70	8310	8750	2640	2780
Avr.	-							11377	11523	3550	3600
	-	2.09	2.00	3.14	6.57	240	36.53	9080	9080	2890	2890
B_{20}	2-28	2.12	2.02	3.20	6.78	253	37.30	7810	8170	2440	2550
	-	2.11	2.05	3.30	6.96	255	36.66	10020	10020	3040	3040
Avr.	-							8970	9090	2790	2830
	-	2.08	1.99	3.11	6.48	237	36.58	8100	8100	2600	2600
C_{20}	2-28	2.07	1.99	3.11	6.45	238	36.90	4200	6410	1350	2060
	-	2.08	2.05	3.30	6.87	252	36.66	9120	9120	2760	2760
Avr.	-							7140	7877	2240	2470
	-	2.08	2.05	3.30	6.87	255	37.12	10530	11690	3190	3540
A_{30}	3-1	2.07	2.02	3.20	6.63	242	36.50	6560	7700	2040	2400
	-	2.10	2.04	3.27	6.87	256	37.30	10540	10540	3230	3230
Avr.	-							9210	9977	2820	3060
	-	2.00	1.99	3.11	6.22	216	34.72	5650	7820	1820	2510¶
B_{30}	3-1	2.11	2.02	3.20	6.75	251	37.20	8090	8090	2590	2530
	-	2.12	2.04	3.27	6.93	253	36.52	12560	12560	3840	3840‡
Avr.	-							10325	10325	3250	3250
	-	2.11	2.02	3.20	6.75	254	37.66	12070	12070	3770	3770‡
C_{30}	3-1	2.09	1.97	3.05	6.38	237	37.14	6380	7500	2090	2450
	-	2.10	2.00	3.14	6.60	248	37.58	10690	10690	3490	3490
Avr.	-							9713	10087	3120	3240
	-	2.12	2.01	3.17	6.72	244	36.32	5260	5560	1660	1750
A_{40}	3-3	2.09	2.00	3.14	6.57	235	35.77	8910	8910	2840	2840
	-	2.11	2.04	3.27	6.90	252	36.52	9750	9750	2980	2980
Avr.	-							7973	8073	2490	2520
	-	2.13	2.00	3.14	6.69	242	36.18	9220	9220	2930	2930
B_{40}	3-3	2.14	2.04	3.27	6.72	255	37.96	7430	7430	2270	2270
	-	2.14	2.00	3.14	6.72	242	36.00	6420	6420	2040	2040‖
Avr.	-							7690	7690	2410	2410
	-	2.14	2.03	3.23	6.92	255	36.88	7500	7500	2320	2320‖
C_{40}	3-3	2.11	2.04	3.27	6.90	251	36.40	6570	6570	2010	2010*
	-	2.12	2.04	3.27	6.93	254	36.66	6660	6660	2040	2040*
Avr.	-							6660	6660	2040	2040
Average of Averages.											
A - B - C										3930	4320
A_{10} - B_{10} - C_{10}										4020	4020
A_{20} - B_{20} - C_{20}										2860	2970
A_{30} - B_{30} - C_{30}										3060	3180
A_{40} - B_{40} - C_{40}										2310	2320
Average of Highest Breaks.											
A - B - C										4240	4910
A_{10} - B_{10} - C_{10}										4550	4550
A_{20} - B_{20} - C_{20}										3310	3310
A_{30} - B_{30} - C_{30}										3610	3720
A_{40} - B_{40} - C_{40}										2770	2740

†Failed with report. *Chip off of base. Omit. §Failed with slight report.
‡Failed with light report. ‖Bad end. Omit. ¶Cavity in base. Omit.

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 52 weeks.

(Mortar Specimens)

Serial Number	Spec's made 1916 Date	Dimensions		Area in sq. in	Vol. in cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.05	2.05	3.30	6.77	258	38.1	12570	12570	3809	3809
A	2-23	2.05	2.00	3.14	6.44	241	37.4	10380	10380	3304	3304
	-	2.07	2.00	3.14	6.50	260	40.0	15890	15890	5056	5056
Avr.	-							12946	12946	4056	4056
	-	2.05	2.00	3.14	6.44	244	37.9	12110	12110	3859	3859
B	2-23	2.04	2.00	3.14	6.41	238	37.1	11000	13000	3502	4140
	-	2.03	2.00	3.14	6.37	237	37.2	8000	10210	2547	3252
Avr.	-							10370	11773	3303	3750
	-	2.04	2.00	3.14	6.41	246	38.4	12000	13650	3822	4350
C	2-26	2.04	2.00	3.14	6.41	245	38.2	10000	11850	3180	3772
	-	2.02	2.02	3.21	6.48	248	38.3	15000	15770	4672	4912
Avr.	-							12333	13757	4225	4345
	-	2.00	2.00	3.14	6.28	257	40.9	11500	11890	3660	3782
A_{10}	2-26	2.04	2.00	3.14	6.41	239	37.3	11550	11550	3678	3679
	-	2.00	2.00	3.14	6.28	260	41.4	12000	12000	3821	3820
Avr.	-							11683	11813	3720	3760
	-	2.08	2.00	3.14	6.53	246	37.7	13000	13600	4138	4331
B_{10}	2-26	2.05	2.02	3.21	6.58	248	37.7	10600	10680	3300	3327
	-	2.00	1.93	2.93	5.86	238	40.7	14500	14500	4950	4948
Avr.	-							12700	12927	4129	4202
	-	2.10	2.00	3.14	6.59	256	38.9	9506	9500	3240	3025
C_{10}	2-26	2.06	2.00	3.14	6.47	256	39.6	14200	14250	4540	4537
	-	2.05	2.00	3.14	6.43	242	37.6	10800	10800	3440	3440
Avr.	-							11500	11517	3740	3667
	-	2.12	2.00	3.14	6.66	256	38.4	8000	11970	2548	3812
A_{20}	2-28	2.12	2.00	3.14	6.66	255	38.3	12860	12860	4068	4069
	-	2.04	2.04	3.27	6.67	259	38.8	13000	14120	3976	4320
Avr.	-							11287	12983	3531	4067
	-	2.05	2.00	3.14	6.43	254	39.5	8000	9940	2547	3166
B_{20}	2-28	2.04	2.00	3.14	6.40	252	39.4	11500	11680	3661	3720
	-	2.05	2.00	3.14	6.43	255	39.7	11610	11610	3700	3700
Avr.	-							10370	11077	3303	3529
	-	2.08	2.00	3.14	6.53	244	37.4	6200	6860	1973	2184
C_{20}	2-28	2.05	2.02	3.21	6.58	257	39.1	9000	9260	2810	2884
	-	2.02	2.02	3.21	6.48	255	39.3	8500	8800	2647	2740
Avr.	-							7900	8307	2477	2607
	-	2.10	2.00	3.14	6.59	257	39.0	7000	7100	2228	2260
A_{30}	3-1	2.04	1.98	3.08	6.28	239	38.1	10100	10470	3279	3398
	-	2.07	2.04	3.27	6.77	258	38.1	7260	7260	2220	2220
Avr.	-							8120	8277	2576	2626
	-	2.07	2.00	3.14	6.50	244	37.6	5500	5760	1751	1834
B_{30}	3-1	2.07	2.04	3.27	6.77	257	38.0	8740	8740	2673	2672
	-	2.06	2.00	3.14	6.47	244	37.7	10260	10260	3268	3268
Avr.	-							8166	8253	2564	2591
	-	2.06	2.00	3.14	6.47	256	39.6	6400	6400	2039	2039
C_{30}	3-1	2.04	2.00	3.14	6.41	252	39.3	8470	8970	2857	2857
	-	2.05	2.00	3.14	6.43	251	39.1	6740	6740	2140	2144
Avr.	-							7203	7370	2345	2347
	-	2.05	1.98	3.08	6.31	239	37.9	6120	6260	1987	2032
A_{40}	3-3	2.10	2.00	3.14	6.59	253	38.4	9290	9340	2957	2975
	-	2.08	2.00	3.14	6.53	240	36.8	8425	8425	2681	2680
Avr.	-							7945	8008	2542	2562
	-	2.10	2.00	3.14	6.59	252	38.2	5980	5980	1904	1904
B_{40}	3-3	2.10	2.00	3.14	6.59	246	37.4	5870	5870	1870	1870
	-	2.10	2.00	3.14	6.59	252	38.2	7000	7100	2230	2260
Avr.	-							6283	6317	2001	2011
	-	2.08	2.00	3.14	6.53	251	38.5	6000	6430	1910	2047
C_{40}	3-3	2.10	2.00	3.14	6.59	249	37.8	4480	4480	1428	1428
	-	2.11	2.00	3.14	6.62	250	37.8	7170	7170	2282	2282
Avr.	-							5883	6027	1873	1919
Average of Averages.											
A - B - & C										3860	4050
A_{10} - B_{10} & C_{10}										3863	3876
A_{20} - B_{20} & C_{20}										3104	3401
A_{30} - B_{30} & C_{30}										2495	2521
A_{40} - B_{40} & C_{40}										2139	2164
Average of Highest Breaks.											
A - B & C										4529	4703
A_{10} - B_{10} & C_{10}										4468	4435
A_{20} - B_{20} & C_{20}										3526	3641
A_{30} - B_{30} & C_{30}										9404	3174
A_{40} - B_{40} & C_{40}										2490	2506

Series I

RESULTS OF COMPRESSION TESTS.

Tested at age of 104 weeks.

(Mortar Specimens)

Serial	Spec's made 1916 Date	Dimension		Area in sq. in	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.10	2.04	3.27	6.87	261	37.99	11200	17880	3425	5467
A	2-23	2.10	1.96	3.02	6.34	239	37.70	8570	8730	2838	2891
	-	2.05	1.98	3.08	6.31	243	38.51	8970	9640	2912	3130
Avr.	-							9580	12083	3058	3830
	-	2.09	2.01	3.27	6.83	258	37.77	9350	10110	2859	3092
A_{10}	2-26	2.08	2.04	3.27	6.70	260	38.80	8550	12200	2615	3731
	-	2.11	2.00	3.14	6.62	260	39.29	8000	8400	2548	2675
Avr.	-							8633	10237	2674	3166
	-	2.14	2.02	3.20	6.85	256	37.37	11960	11960	3738	3738
A_{20}	2-28	2.11	1.98	3.08	6.50	249	38.31	8310	8310	2698	2698
	-	2.12	2.02	3.20	6.78	261	38.50	8050	9540	2516	2981
Avr.	-							9440	9937	2984	3139
	-	2.11	2.04	3.27	6.90	258	37.39	7250	7250	2217	2217
A_{30}	3-1	2.15	2.05	3.30	7.10	262	36.90	6370	6370	1930	1930
	-	2.06	1.96	3.02	6.22	240	38.58	10030	10030	3321	3321
Avr.	-							7883	7883	2489	2489
	-	2.10	2.01	3.17	6 65	247	37.14	5920	5920	1868	1868
A_{-40}	3-3	2.10	2.01	3.17	6.65	254	38.20	7540	7540	2378	2378.
	-	2.10	2.01	3.17	6.65	254	38.20	7160	7160	2259	2259
Avr.	-							6873	6873	2168	2168
	-										
B	2-23										
	-										
Avr.	-										
	-										
	-	2.05	1.98	3.08	6.31	235	37.24	5970	6600	1938	2143
B_{10}	2-26	2.05	1.95	2.98	6.11	237	38.79	12150	12970	4077	4352
	-	2.07	1.98	3.08	6.38	235	36.74	10500	10600	3409	3442
Avr.	-							9540	10057	3141	3312
	-	2.13	2.01	3.17	6.75	258	38.22	9040	10210	2852	3221
B_{20}	2-28	2.08	1.96	3.02	6.28	242	38.54	11270	11270	3732	3732
	-	2.07	1.97	3.05	6.31	242	38.35	9440	9440	3095	3095
Avr.	-							9917	10307	3226	3349
	-	2.13	1.99	3.11	6.62	245	37.01	8930	8930	2871	2871
B_{30}	3-1	2.10	1.98	3.08	6.47	244	37.71	6570	7300	2133	2370
	-	2.11	1.98	3.08	6.50	246	37.85	7550	7550	2451	2451
Avr.	-							7683	7927	2485	2564
	-	2.10	1.98	3.08	6.47	239	36.94	9080	9080	2948	2948
B_{40}	3-3	2.12	1.98	3.08	6.53	242	37.06	8780	8780	2851	2851
	-	2.15	2.02	3.20	6.88	249	36 19	8140	8140	2531	2531
Avr.	-							8667	8667	2777	2777
	-	2.10	1.97	3.05	6.40	236	36.88	15890	15890	5210	5210
C	2-26	2.10	1.97	3.05	6.40	240	37.50	19960	19960	6544	6544
	-	2.10	1.97	3.05	6.40	239	37.34	14240	14240	4669	4669
Avr.	-							16697	16697	5474	5474
	-	2.09	1.97	3.05	6.37	243	38.15	7800	8350	2557	2738
C_{10}	2-26	2.09	1.97	3.05	6.37	240	37.68	11570	11570	3793	3793
	-	2.10	2.02	3.20	6.72	255	37.95	7300	8490	2281	2653
Avr.	-							8890	9470	2877	3061
	-	2.10	2.02	3.20	6.72	257	38.24	7970	7930	2491	2478
C_{20}	2-28	2.06	2.00	3.14	6.47	239	36.94	7360	7360	2344	2344
	-	2.10	2.02	3.20	6.72	256	38.10	7730	7730	2416	2416
Avr.	-							7687	7673	2417	2413
	-	2.10	1.98	3.08	6.47	241	37.25	6780	6780	2201	2201
C_{30}	3-1	2.12	2.01	3.17	6.72	249	37.05	4280	4560	1350	1438
	-										
Avr.	-							5530	5670	1776	1819
	-	2.08	1.99	3.11	6.47	238	36.78	7240	7240	2328	2328
C_{40}	3-3	2.08	1.99	3.11	6.47	239	36.94	6840	6840	2199	2199
	-										
Avr.	-							7040	7040	2264	2264
		Average of Averages.									
A - C											4652
A_{10}, B_{10}, C_{10}											3180
A_{20}, B_{20}, C_{20}											2967
A_{30}, B_{30}, C_{30}											2291
A_{40}, B_{40}, C_{40}											2403

Series II

RESULTS OF TENSION TESTS.

(Neat Specimens)

Serial Number	Spec's made 1916 Date	24 hours	1 week	4 weeks	8 weeks	12 weeks	24 weeks	52 weeks	104 weeks
	-	424	696	618	785	700	705	645	707
A_0	6-1	407	632	842	701	695	710	610	
	-	349	728	709	749	794	880	565	
Avr.	-	393+	685	776	745	730	765	607	707
	-	327	563	618	611	630	652	685	737
A_{25}	6-2	304	486	527	648	617	675	500	591
	-	332	635	636	587	686	561	705	620
Avr.	-	321	599	627	615	644	629	630	649
	-	210	442	562	569	553	540	520	655
A_{50}	6-2	235	416	584	558	492	590	610	520
	-	293	435	599	574	628	500	575	640
Avr.	-	246	431	582	567	558	543	568	605
	-	61	120	231	276	272	220		
A_{75}	6-15	60	170	233	224	298	237		
	-	28	136	94	228	278	334		
Avr.	-	60+	153	232	242	283	263		
	-		124	230		215	243	230	370
$A_{87\ 1/2}$	7-10		107	278		275	312	277	335
	-		118	247		256	288	222	320
Avr.	-		116	252		249	281	243	342
	-		84	167	185	No	236	210	55
$A_{93\ 3/4}$	7-12		76	165	167	No	244	206	135
	-		62	147	182	No	201	245	
Avr.	-		74	160	178	No	227	220	95
	-		No			No	00		30
$A_{96\ 7/8}$	8-8		No			No	30		
	-		No			No	26		
Avr.	-		No			No	28		30
	-	67	261	410	470	355	311	455	
A_{75}*	8-11	57	238	372	411	395	338	476	
Special	-	66		392		405	289		
Avr.	-	63	250	391	441	385	313	465	
	-	307	729	396	828	730	754	720	770
B_0	8-9	428	690	760	755	635	730	727	795
	-	448	650	835	771	807	560	642	760
Avr.	-	424	690	664	785	724	681	696	775
	-	422	581	653	560	696	807	725	698
B_{25}	8-10	378	637	775	715	752	639	685	708
	-	389	584	686	730	649	659	710	685
Avr.	-	396	601	705	668	699	701	707	697
	-	219	456	578	605	580	560	635	615
B_{50}	8-11	181	460	550	598	593	595	625	645
	-	206	461	596	570	500	560	589	645
Avr.	-	202	459	575	591	558	572	616	635
	-	29	240	375	461	432	456	482	495
B_{75}	8-14	59	259	430	445	510	491	482	482
	-	64	255	380	523	427	421	450	505
Avr.	-	51	251	395	476	456	456	471	494
	-	No	92	220	243	265	271	290	303
$B_{87\ 1/2}$	8-15	No	102	206	259	256	278	262	300
	-	No	101	226	237	233	285	320	350
Avr.	-	No	98	217	246	251	278	291	318
	-	No	70	128	206	189	218	256	180
$B_{93\ 3/4}$	8-15	No	73	150	194	220	234	272	
	-	No	70	165	180	209	221	263	
Avr.	-	No	71	144	193	206	224	264	180
	-	No	No	45	No	No	33	40	45
$B_{96\ 7/8}$	8-16	No	No	21	No	No	42	81	70
	-	No	No	21	No	No	52	85	
Avr.	-	No	No	29	No	No	42	69	57
		Average of Averages.							
A_0 - B_0		408	687	720	765	727	723	652	741
A_{25} - B_{25}		358	600	666	641	671	665	668	673
A_{50} - B_{50}		224	445	578	579	558	558	592	620
A_{75} - B_{75}		56	202	314	359	369	359		
$A_{87\ 1/2}$ - $B_{87\ 1/2}$			107	235		250	279	267	330
$A_{93\ 3/4}$ - $B_{93\ 3/4}$			73	152	186		225	242	137
		Average of Highest Breaks.							
A_0 - B_0		436	728	839	807	801	817	686	751
A_{25} - B_{25}		377	636	706	689	719	741	715	723
A_{50} - B_{50}		256	452	598	589	611	593	622	650
A_{75} - B_{75}		62	215	332	399	404	413		
$A_{87\ 1/2}$ - $B_{87\ 1/2}$			113	252		270	299	298	360
$A_{93\ 3/4}$ - $B_{93\ 3/4}$			79	166	190		239	258	157

Series II

RESULTS OF TENSION TESTS.

(Mortar Specimens)

Serial Number	Date made 1916 Date	1 week	4 weeks	8 weeks	12 weeks	24 weeks	52 weeks	104 weeks
	-	306	390	476	442	467	405	415
A_0	6-1	291	415	491	511	477	420	414
Avr.	-	295	423	379	470	435	375	426
	-	297+	409	484	474	459	400	418
	-	282	377	440	373	403	395	410
A_{25}	6-2	280	353	464	458	385	400	370
	-	256	420	395	405	414	420	432
Avr.	-	273	383	433	412	401	405	407
	-	216	301	342	380	410	325	345
A_{50}	6-2	208	310	394	393	416	345	418
	-	203	262	355	368	395	362	385
Avr.	-	209	291	364	380	407	344	383
	-	99	185	239	267	262	275	300
A_{75}	6-15	106	192	241	304	262	270	260
	-	92	187	226	262	290	300	
Avr.	-	99	188	235	278	271	282	280
	-	36	53		75	84	85	
$A_{87\ 1/2}$	7-10	26	56		83	92	77	
	-		60		83	104	100	70
Avr.	-	31	56		80	93	87	70
	-	No	No	No	No	No		
$A_{93\ 3/4}$	7-12	No	No	No	No	No		
	-	No	No	No	No	No		
Avr.	-	No	No	No	No	No		
	-	No	No					
$A_{96\ 7/8}$	8-8	No	No					
	-	No	No					
Avr.	-	No	No					
	-	264	381	400	412	400	350	430
B_0	8-9	197	347	341	412	455	285	405
	-	242	393	465	452	468	355	370
Avr.	-	253	374	432	425	441	330	402
	-	270	354	385	345	383	399	308
B_{25}	8-10	279	319	365	357	424	362	386
	-	265	311	307	377	363	308	310
Avr.	-	271	328	352	360	390	356	335
	-	120	205	255	297	283	315	275
B_{50}	8-11	140	190	295	263	303	307	255
	-	136	227	265	264	335	300	275
Avr.	-	132	207	272	275	307	307	268
	-	69	147	178	183	178	245	210
B_{75}	8-14	62	145	164	210	194	215	240
	-	64	144	165	174	218	193	
Avr.	-	64	145	169	189	197	218	225
	-	No	73	86	107	137	142	115
$B_{87\ 1/2}$	8-15	No	52	87	106	132	127	110
	-	No	35	79	85	106	165	80
Avr.	-	No	62	84	100	125	145	102
	-	No	No	No	63	88	98	
$B_{93\ 3/4}$	8-15	No	No	No	40	62	63	90
	-	No	No	No	52	64	85	
Avr.	-	No	No	No	52	71	82	90
	-	No	No					
$B_{96\ 7/8}$	8-16	No	No					
	-	No	No					
Avr.	-	No	No					
		Average of Averages.						
A_0 - B_0		274	392	458	449	450	365	410
A_{25} - B_{25}		272	355	392	386	395	380	371
A_{50} - B_{50}		170	249	318	328	357	326	325
A_{75} - B_{75}		82	166	202	233	234	250	252
$A_{87\ 1/2}$ - $B_{87\ 1/2}$		—	59	—	90	109	116	86
		Average of Highest Breaks.						
A_0 - B_0		285	408	478	481	472	388	428
A_{25} - B_{25}		280	387	424	417	419	410	409
A_{50} - B_{50}		178	268	344	345	375	338	346
A_{75} - B_{75}		87	169	209	257	254	272	270
$A_{87\ 1/2}$ - $B_{87\ 1/2}$			66		95	120	132	92

Series II

RESULTS OF COMPRESSION TESTS.

Series Number	Specimen made	Stress in pounds ptr square inch							
		4 weeks Neat	4 weeks Mortar	24 weeks Neat	24 weeks Mortar	52 weeks Neat	52 weeks Mortar	104 weeks Neat	104 weeks Mortar
		8200	1954	5430	2535	8615	2548	13936	2095
A_0		7350	1623	9180	2500	6350	2070	14212	2255
		5490	2171	9350	2810	4140	2385	15256	2095
Av.		7013	1916	7987	2615	6368	2334	14468	2148
		7570	1918	7430	1910	8879	3274	8662	2950
B_0		6890	1571	7820	2020	8060	3869	9070	1735
		6150	1678	8780	2542	7293	3965	7910	
Av.		6870	1722	8010	2160	8077	3703	8547	2343
		6520	1765	7490	3000	6529	2045	8642	2900
A_{25}		5770	2218	10790	2670	5303	2468	8880	1685
		7140	1980	8740	2315	6768	2618	6637	
Av.		6477	1988	9007	2661	6200	2377	8053	2293
		6280	2090	6940	2050	7055	1720	5390	2148
B_{25}		6660	1974	7420	2020	7982	2270	5550	1313
		6350	1875	7525	2285	6864	2448		
Av.		6430	1980	7295	2115	7300	2146	5470	1733
		4450	1434	5300	2175	6019	2500	4025	1895
A_{50}		4370	1474	5120	2180	8089	1781	2381	815
		4130	1523	5300	2215	5662	2131	4435	
Av.		4317	1477	5240	2190	6590	2137	3614	1355
		3452	1028	4750	897	4373	730	4348	
B_{50}		4060	898	5620	955	6527	1152	5291	
		5140	889	6390	1700	7120	601	4340	
Av.		4217	938	5586	1195	6007	828	4660	
		1511		2300	1170	1392	965	1422	938
A_{75}		1292	824	2450	1221	1115	1076	1609	768
		1038	753	1893	1171	1895	771	1135	1010
Av.		1280	789	2214	1187	146.	937	1389	905
		1827	311	2460	335	1786	637	2249	508
B_{75}		2157	486	2620	480	2461	685	2543	507
		1776	503	2080	470	2338	503	2431	698
Av.		1920	431	2386	431	2195	608	2408	571
		1141	338	1862	534	1197	354		
$A_{87\ 1/2}$		947	324	1873	420	398	573		
		1310	360	2240	589		637		
Av.		1133	340	1992	514	798	521		
		868	342	1055	382	1169	1340	1234	518
$B_{87\ 1/2}$		782	311	1014	368	1115	929	1211	570
		814	272	1040	308	1227	1036		332
Av.		821	308	1036	353	1170	1102	1222	473
		531	No	746	68.7	924		781	No
$A_{93\ 3/4}$		626	No	737	56.4	1010		810	No
		498	No	962.5	84.6	1290		705	No
Avr.		552	No	815	69.9	1075		765	No
		564	99	961	245	949	159	848	194
$B_{93\ 3/4}$		648	71	946	194	639	153	1290	433
		338	59	795	161	982	252	1273	
Av.		517	76	901	202	857	188	1137	314
		No	No	31.9			No	No	
$A_{96\ 7/8}$		No	No	25.3		19			
		No	No	43.0		25			
Av.		No	No	33.4		22	No	No	
		30	318	61.2		61	284	No	
$B_{96\ 7/8}$		43	274	69.7		48		No	
		16	164	83.8		63			
Av.		29	252	71.5		57	284	No	
				Average of Averages					
$A_0 - B_0$		6942	1819	7999	2388	7223	3019	11508	2245
$A_{25} - B_{25}$		6454	1984	8151	2388	6750	2262	4893	3882
$A_{50} - B_{50}$		4267	1208	5413	1693	5835	1483	4137	
$A_{75} - B_{75}$		1600	610	2300	809	1831	773	1899	738
$A_{87\ 1/2} - B_{87\ 1/2}$		977	324	1514	434	984	820		
$A_{93\ 3/4} - B_{93\ 3/4}$		535		858	136	966		951	
		Average of Highest Breaks.							
$A_0 - B_0$		7885	2045	9065	2676	8747	3257	11959	2603
$A_{25} - B_{25}$		6900	2154	9158	2643	7375	2033	5514	4225
$A_{50} - B_{50}$		4795	1272	5845	1958	7605	1826	4863	
$A_{75} - B_{75}$		1834	664	2535	850	2178	880	2076	854
$A_{87\ 1/2} - B_{87\ 1/2}$		1089	351	1648	486	1212	989		
$A_{93\ 3/4} - B_{93\ 3/4}$		637		962	165	1136		1050	
$A_{96\ 7/8} - B_{96\ 7/8}$								No	

For detailed results see Tables 17 to 24 inclusive.

Series II

RESULTS OF COMPRESSION TESTS.

Tested at age of 4 weeks.
(Neat Specimens)

Series Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height	Diam.			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.00	1.97	3.05	6.10	224	36.71	10240	24420	3570	8200
A_0	6-8	2.03	2.01	3.17	6.44	240	37.29	13810	23340	4360	7350
	-	1.93	2.02	3.20	6.18	224	37.25	8240	17580	2575	5490
Avr.	-							10763	21780	3502	7013
	-	2.06	2.04	3.27	6.74	236	35.04	7470	21330	2285	6520
A_{25}	6-9	2.08	2.05	3.30	6.87	244	35.50	8890	19050	2694	5770
	-	2.05	2.04.	3.27	6.70	240	35.80	6830	23380	2090	7140
Avr.	-							7730	21253	2356	6477
	-	2.02	2.00	3.14	6.34	215	33.91	9170	13990	2923	4450
A_{50}	6-12	2.05	1.98	3.08	6.32	218	34.49	5000	13490	1624	4370
	-	2.06	1.98	3.08	6.35	218	34.31	8800	12720	2855	4130
Avr.	-							7657	13400	2467	4317
	-	2.08	2.03	3.24	6.74	212	31.42	4900	4900	1511	1511
A_{75}	6-19	2.04	1.98	3.08	6.28	199	31.70	600	3980	195	1292
	-	2.04	2.00	3.14	6.40	199	31.11	2820	3260	898	1038
Avr.	-							2773	4047	868	1280
	-	2.12	2.06	3.34	7.07	220	31.11		3810		1141
$A_{87\ 1/2}$	7-12	2.11	2.02	3.20	6.75	217	32.15	2640	3030	824	947
	-	2.11	2.00	3.14	6.62	210	31.72	3780	4110	1203	1310
Avr.	-							3210	3650	1014	1133
	-	2.12	2.02	3.20	6.78	215	31.72	1540	1700	481	531
$A_{93\ 3/4}$	8-7	2.12	2.06	3.34	7.07	228	32.25		2030		626
	-	2.20	1.97	3.05	6.71	209	31.11	920	1520	302	498
Avr.	-							1230	1750	392	552
	-										No
$A_{96\ 7/8}$	8-8										No
	-										No
Avr.	-										No
	-	2.10	2.08	3.40	7.14	256	35.88	21420	25770	6310	7570
B_0	8-9	2.04	2.05	3.30	6.74	239	35.45	21990	22760	6660	6890
	-	2.08	2.04	3.27	6.80	240	35.29	18690	20120	5720	6150
Avr.	-							20700	22883	6230	6870
	-	2.10	1.99	3.11	6.53	229	35.08	17670	19540	5680	6280
B_{25}	8-10	2.10	2.02	3.20	6.72	248	36.91	18300	21330	5720	6660
	-	2.07	1.99	3.11	6.44	229	35.59		19760		6350
Avr.	-							17985	20210	5700	6430
	-	2.08	1.98	3.08	6.41	224	34.92		10630		3452
B_{50}	8-11	2.08	2.02	3.20	6.66	233	34.95	12390	12980	3870	4060
	-	2.10	2.03	3.24	6.80	237	34.85		16620		5140
Avr.	-							12390	13410	3870	4217
	-	2.14	1.98	3.08	6.59	224	34.00	5250	5630	1705	1827
B_{75}	8-14	2.14	2.01	3.17	6.78	229	33.75		6840		2157
	-	2.08	2.02	3.20	6.66	219	32.85		5680		1776
Avr.	-							5250	6050	1705	1920
	-	2.08	2.04	3.27	6.80	224	32.94		2840		868
$B_{87\ 1/2}$	8-15	2.10	2.08	3.40	7.14	230	32.20		2660		782
	-	2.08	2.09	3.43	7.14	231	32.35		2795		814
Avr.	-								2765		821
	-	2.14	2.00	3.14	6.71	216	32.20		1770		564
$B_{93\ 3/4}$	8-15	2.10	2.05	3.30	6.94	220	31.70		2140		648
	-	2.12	2.02	3.20	6.78	216	31.85		1400		338
Avr.	-								1770		517
	-	2.08	1.97	3.05	6.34	209	32.97		90		30
$B_{96\ 7/8}$	8-16	2.10	2.04	3.27	6.86	224	32.61		140		43
	-	2.05	2.00	3.14	6.43	206	32.05		50		16
Avr.	-								93		29
		Average of Averages.									
A_0 - B_0										4866	6941
A_{25} - B_{25}										4028	6452
A_{50} - B_{50}										3169	4267
A_{75} - B_{75}										1286	1600
$A_{87\ 1/2}$ - $B_{87\ 1/2}$										1014	977
$A_{93\ 3/4}$ - $B_{93\ 3/4}$										392	535
		Average of Highest Breaks.									
A_0 - B_0										5510	7885
A_{25} - B_{25}										4207	6900
A_{50} - B_{50}										3397	4795
A_{75} - B_{75}										1608	1834
$A_{87\ 1/2}$ - $B_{87\ 1/2}$										1203	1004
$A_{93\ 3/4}$ - $B_{93\ 3/4}$										481	637

Series II

RESULTS OF COMPRESSION TESTS.

Tested at age of 24 weeks.

(Neat Specimens)

Serial Number	Date made 1916	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress		
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.	
	-	2.00	1.96	3.02	6.04	226	37.40	11980	16385	3962	5430	
A_0	6-8	2.00	1.97	3.05	6.10	229	37.50	20000	28000	6550	9180*	
	-	1.98	1.97	3.05	6.04	231	38.23	23560	28550	7720	9350	
Avr.	-							18513	24312	6077	7987	
	-	2.06	2.01	3.17	6.54	236	36.10	17770	23790	5600	7490	
A_{25}	6-9	2.04	2.02	3.20	6.55	244	37.25	9500	34520	2970	10790	*
	-	2.08	2.02	3.20	6.67	245	36.75	17980	27980	5620	8740	
Avr.	-							15083	28763	4730	9007	
	-	2.10	2.03	3.24	6.80	235	34.55	12370	17190	3815	5300	
A_{50}	6-12	2.03	1.98	3.08	6.26	217	34.65	10000	15715	2248	5120	
	-	2.06	1.98	3.08	6.35	221	34.80	13400	16320	4350	5300	
Avr.	-							11923	16408	3471	5240	
	-	2.10	2.04	3.27	6.87	217	31.60	7320	7520	2240	2300	
A_{75}	6-19	2.05	1.98	3.08	6.32	206	32.60	7480	7540	2430	2450	
	-	2.04	1.99	3.11	6.35	200	31.51	5890	5890	1893	1893	
Avr.	-							6897	6983	2188	2214	
	-	2.06	2.05	3.30	6.80	222	32.46	6150	6150	1862	1862	
$A_{87\ 1/2}$	7-12	2.05	1.97	3.05	6.25	211	34.75	5720	5720	1873	1873	†
	-	2.06	2.00	3.14	6.48	210	32.40	7030	7030	2240	2240	
Avr.	-							6300	6300	1992	1992	
	-	2.10	2.00	3.14	6.60	217	32.90	2020	2340	650	746	
$A_{93\ 3/4}$	8-7	2.09	1.99	3.11	6.50	220	33.85	2100	2290	675	737.0	
	-	2.10	1.99	3.11	6.54	210	32.10	2800	2990	901	962.5	
Avr.	-							2306	2540	742	815	
	-	1.90	2.00	3.14	5.97	199	33.30	80	100	25.5	31.9	
$A_{96\ 7/8}$	8-8	1.89	2.01	3.17	5.99	192	32.10	80	80	25.3	25.3	
	-	2.00	2.00	3.14	6.28	197	31.39	90	135	28.6	43.0	
Avr.	-							83	105	26.5	33.4	
	-	2.07	2.04	3.27	6.77	245	36.20	17800	24320	5440	7430	
B_0	8-9	2.08	2.03	3.24	6.74	243	36.10	16740	25360	5170	7820	
	-	2.07	2.04	3.27	6.77	244	36.09	18300	28660	5590	8780	
Avr.	-							17613	26113	5400	8010	
	-	2.10	2.10	3.46	7.24	253	34.9	19000	24000	5480	6940	
B_{25}	8-10	2.11	2.09	3.43	7.24	255	35.25	9500	25420	2770	7420	
	-	2.10	2.09	3.43	7.21	251	34.80	14000	25830	4080	7525	
Avr.	-							14166	25083	4110	7295	
	-	2.04	2.04	3.27	6.68	239	35.79	9800	15530	2990	4750	
B_{50}	8-11	2.04	2.04	3.27	6.68	237	35.50	11540	18370	3530	5620	
	-	2.04	2.04	3.27	6.68	234	35.10	15000	20940	4580	6390	
Avr.	-							12113	18280	3700	5586	
	-	2.08	2.01	3.17	6.60	232	35.20	7500	7800	2370	2460	
B_{75}	8-14	2.06	2.01	3.17	6.53	219	33.59	7000	8300	2210	2620	
	-	2.00	2.04	3.27	6.54	219	33.59	6400	6800	1959	2080	
Avr.	-							6966	7633	2179	2386	
	-	2.08	2.08	3.40	7.07	222	31.40	3590	3590	1055	1055	
$B_{87\ 1/2}$	8-15	2.12	2.08	3.40	7.21	221	30.61	2850	3450	838	1014	
	-	2.08	2.13	3.56	7.40	232	31.39	3710	3710	1040	1040	
Avr.	-							3383	3583	977	1036	
	-	2.06	2.06	3.33	6.86	223	32.5	3220	3220	961	961	
$B_{93\ 3/4}$	8-15	2.07	2.06	3.33	6.90	223	32.3	3150	3150	946	946	
	-	2.06	2.06	3.33	6.86	219	31.9	2280	2650	685	795	
Avr.	-							2883	3006	864	901	
	-	2.04	2.04	3.27	6.68	225	33.7	200	200	61.2	61.2	§
$B_{96\ 7/8}$	8-16	2.12	2.05	3.30	7.01	227	32.4	230	230	69.7	69.7	
	-	2.10	2.10	3.46	7.27	227	31.2	290	290	83.8	83.8	
Avr.	-							240	240	71.5	71.5	

Average of Averages.

A_0 - B_0	5738	7998
A_{25} - B_{25}	4420	8151
A_{50} - B_{50}	3585	5413
A_{75} - B_{75}	2183	2300
$A_{87\ 1/2}$ - $B_{87\ 1/2}$	1484	1514
$A_{93\ 3/4}$ - $B_{93\ 3/4}$	803	856

Average of Highest Breaks.

A_0 - B_0	6650	9065
A_{25} - B_{25}	5550	9157
A_{50} - B_{50}	4465	5845
A_{75} - B_{75}	2400	2535
$A_{87\ 1/2}$ - $B_{87\ 1/2}$	1647	1647
$A_{93\ 3/4}$ - $B_{93\ 3/4}$	931	962
$A_{96\ 7/8}$ - $B_{96\ 7/8}$	56.0	63.0

*4 days late. †2 days late. §Material very soft.

Series II

RESULTS OF COMPRESSION TESTS.

Tested at age of 52 weeks.

(Neat Specimens)

Serial Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.05	2.00	3.14	6.44	241	37.42	10000	27050	3185	8615
A_{-0}	6-8	2.00	2.00	3.14	6.28	267	42.52	12800	19940	4076	6350
	-	2.00	2.00	3.14	6.28	232	36.94	3800	13000	1210	4140
Avr.	-							8867	19997	2824	6368
	-	2.00	2.00	3.14	6.28	230	36.62	8000	20500	2548	6529
A_{-25}	6-9	2.05	2.05	3.30	6.76	237	35.06	9500	17500	2879	5303
	-	2.00	2.00	3.14	6.28	228	36.30	6380	21250	2032	6768
Avr.	-							7960	19750	2486	6200
	-	2.00	2.00	3.14	6.28	217	34.55	10000	18900	3185	6019
A_{-50}	6-12	2.00	2.00	3.14	6.28	234	37.26	11520	25400	3669	8089
	-	2.00	1.95	3.02	6.04	220	36.42	13700	17100	4536	5662
Avr.	-							11740	20467	3797	6590
	-	2.00	2.00	3.14	6.28	202	32.14	4370	4370	1392	1392
A_{-75}	6-19	2.00	2.00	3.14	6.28	202	32.14	3500	3500	1115	1115
	-	2.00	2.00	3.14	6.28	205	32.64	5950	5950	1895	1895
Avr.	-							4607	4607	1467	1467
	-	2.05	2.00	3.14	6.44	222	34.50	3760	3760	1197	1197
$A_{-87\ 1/2}$	7-12	2.10	2.00	3.14	6.59	213	32.32	1250	1250	398	398
	-	2.00	2.00	3.14	6.28	209	33.28				
Avr.	-							2505	2505	798	798
	-	2.00	2.00	3.14	6.28	220	35.03	1900	2900	605	924
$A_{-93\ 3/4}$	8-7	2.00	2.00	3.14	6.28	230	36.62	3170	3170	1010	1010
	-	2.00	2.00	3.14	6.28	230	36.62	3870	4050	1232	1290
Avr.	-							2980	3373	949	1075
	-	2.00	2.00	3.14	6.28	200	31.85				
$A_{-96\ 7/8}$	8-8	2.00	2.00	3.14	6.28	210	33.44	60	60	19	19
	-	2.00	2.00	3.14	6.28	205	32.64	80	80	25	25
Avr.	-							70	70	22	22
	-	2.00	2.00	3.14	6.28	237	37.74	18250	27880	5812	8879
B_{-0}	8-9	2.00	2.00	3.14	6.28	237	37.74	15580	25310	4962	8060
	-	2.00	2.00	3.14	6.28	238	37.94	13640	22900	4344	7293
Avr.	-							15823	25363	5039	8077
	-	2.00	2.04	3.26	6.52	235	36.04	11900	23000	3650	7055
B_{25}	8-10	2.04	2.06	3.33	6.79	252	37.11	14620	26580	4390	7982
	-	2.00	2.02	3.17	6.34	232	36.59	14440	21760	4555	6864
Avr.	-							13653	23780	4198	7300
	-	2.01	2.05	3.30	6.63	227	34.24	12250	14430	3712	4373
B_{-50}	8-11	2.04	2.02	3.17	6.47	235	36.62	12000	20690	3785	6527
	-	2.00	2.02	3.17	6.34	230	36.28	12100	22570	3817	7120
Avr.	-							12117	19230	3771	6007
	-	2.04	2.07	3.36	6.85	240	35.04	5590	6000	1664	1786
B_{-75}	8-14	2.07	2.06	3.33	6.89	239	34.69	6300	8200	1892	2462
	-	2.04	2.02	3.17	6.47	217	33.54	6390	7410	2016	2338
Avr.	-							6093	7203	1857	2195
	-	2.07	2.04	3.26	6.75	222	32.89	3810	3810	1169	1169
$B_{-87\ 1/2}$	8-15	2.06	2.05	3.30	6.80	222	32.65	2440	3680	739	1115
	-	2.05	2.04	3.26	6.68	220	32.93	3170	4000	972	1227
Avr.	-							3140	3830	960	1170
	-	2.06	2.06	3.33	6.86	227	33.09	3160	3160	949	949
$B_{-93\ 3/4}$	8-15	2.05	2.05	3.30	6.80	226	33.24	1640	2110	497	639
	-	2.06	2.06	3.33	6.89	230	33.38	3270	3270	982	982
Avr.	-							2690	2847	809	857
	-	2.05	2.04	3.26	6.68	227	33.98	200	200	61	61
$B_{-96\ 7/8}$	8-16	2.02	2.00	3.14	6.34	212	33.44	100	150	32	48
	-	2.02	2.02	3.17	6.40	212	33.12	200	200	63	63
	-							167	183	52	57

Average of Averages.

A_{-0} - B_{-0}	7222
A_{-25} - B_{25}	6750
A_{-50} - B_{-50}	6298
A_{-75} - B_{-75}	1832
$A_{-87\ 1/2}$ - $B_{-87\ 1/2}$	984
$A_{-93\ 3/4}$ - $B_{-93\ 3/4}$	966
$A_{-96\ 7/8}$ - $B_{-96\ 7/8}$	

Series II

RESULTS OF COMPRESSION TESTS.

Tested at age of 104 weeks.

(Neat Specimens)

Serial Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.00	2.05	3.30	6.60	246	37.30	11400	45990	3455	13936
A_{-0}	6-8	2.02	2.05	3.30	6.66	246	36.95	12600	46900	3818	14212
	-	2.03	1.98	3.08	6.25	229	36.63	25000	46990	8117	15256
Avr.	-									5130	14468
	-	2.02	2.06	3.33	6.73	246	36.55	11110	28780	3336	8642
A_{-25}	6-9	2.03	2.07	3.36	6.82	246	36.51	15000	29840	4464	8880
	-	2.05	2.07	3.36	6.89	245	35.60	4000	22300	1190	6637
Avr.	-									2997	8053
	-	2.02	1.98	3.08	6.22	218	35.10	8820	12400	2863	4025
A_{-50}	6-12	2.05	2.00	3.14	6.44	223	34.61	6600	7480	2101	2381
	-	2.01	2.03	3.23	6.49	237	36.55	9670	14320	2986	4435
Avr.	-									2650	3614
	-	2.06	2.06	3.33	6.86	217	31.61	4230	4740	1271	1422
A_{-75}	6-19	2.05	2.01	3.17	6.50	207	31.80	4990	5100	1573	1609
	-	2.03	1.99	3.11	6.31	202	32.00	3530	3530	1135	1135
Avr.	-									1326	1389
$A_{-87\ 1/2}$	7-12										
Avr.	-										
	-	2.08	2.00	3.14	6.53	220	33.65	2450	2450	781	781
$A_{-93\ 3/4}$	8-7	2.12	2.07	3.36	7.12	220	30.90	2240	2720	667	810
	-	2.13	2.06	3.33	7.09	227	32.00	2220	2350	667	705
Avr.	-									705	765
	-	2.03	1.98	3.08	6.25	204	32.61				No
$A_{-96\ 7/8}$	8-8										
Avr.	-										No
	-	2.08	2.09	3.41	7.09	248	34.95	13000	27000	3815	7910
B_{-0}	8-9	2.08	2.06	3.33	6.93	245	35.35	16240	28840	4872	8662
	-	2.10	2.05	3.30	6.93	247	35.61	15650	29890	4740	9070
Avr.	-									4476	8547
	-	2.20	2.10	3.44	7.57	235	31.05	12840	18540	3680	5390
B_{-25}	8-10	2.12	2.01	3.17	6.73	220	32.65	12650	17660	3980	5550
Avr.	-									3830	5470
	-	2.20	2.08	3.39	7.46	225	30.11	14040	14710	4150	4348
B_{-50}	8-11	2.14	2.04	3.26	6.98	220	31.48	8330	17250	2555	5291
	-	2.16	2.06	3.33	7.19	227	31.55	8630	14420	2591	4340
Avr.	-									3099	4660
	-	2.18	2.04	3.26	7.11	230	32.35	6300	7340	1931	2249
B_{-75}	8-14	2.14	2.01	3.17	6.78	238	35.08	8070	8070	2543	2543
	-	2.20	2.10	3.44	7.57	250	33.00	8230	8360	2392	2431
Avr.	-									2289	2408
	-	2.10	2.08	3.39	7.12	248	34.90	4180	4180	1234	1234
$B_{-87\ 1/2}$	8-15	2.12	2.08	3.39	7.19	242	33.65	4070	4110	1200	1211
	-	2.16	2.06	3.33	7.19	240	33.40				
Avr.	-									1217	1222
	-	2.20	2.00	3.14	6.91	240	34.70	890	2660	283	848
$B_{-93\ 3/4}$	8-15	2.18	2.04	3.26	7.10	237	33.35	3530	4210	1082	1290
	-	2.14	2.01	3.17	6.78	232	34.20	3370	4040	1062	1273
Avr.	-									809	1137
	-	2.10	2.00	3.14	6.60	225	34.05				No
$B_{-96\ 7/8}$	8-16	2.12	2.05	3.30	6.99	230	32.90	40			No
	-										
	-										No

Average of Averages.

A_{-0} - B_{-0}	11508
A_{-25} - B_{-25}	4893
A_{-50} - B_{-50}	4137
A_{-75} - B_{-75}	1899
$A_{87\ 1/2}$ - $B_{87\ 1/2}$	
$A_{-93\ 3/4}$ - $B_{-93\ 3/4}$	951
$A_{-96\ 7/8}$ - $B_{-96\ 7/8}$	No

Series II

RESULTS OF COMPRESSION TESTS.

(Mortar Specimens)

Tested at age of 4 weeks

Serial Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.04	2.05	3.26	6.65	249	37.41		6360		1954
A_{-0}	6-9	2.06	2.02	3.21	6.61	244	36.90		5210		1623
	-	2.05	2.01	3.18	6.51	248	38.05		6900		2171
Avr.	-								6157		1916
	-	2.06	2.02	3.21	6.61	247	37.31		5660		1765
A_{25}	6-9	2.04	2.00	3.14	6.42	242	37.68		6960		2218
	-	2.06	2.00	3.14	6.48	243	37.48		6210		1980
Avr.	-								6277		1988
	-	2.05	1.98	3.08	6.32	235	37.18		4420		1434
A_{50}	6-12	2.10	2.02	3.21	6.75	252	37.31		4730		1474
	-	2.04	1.98	3.08	6.28	235	37.40		4690		1523
Avr.	-								4613		1477
	-	2.10	2.04	3.27	6.85	253	36.95				†
A_{75}	6-19	2.10	2.00	3.14	6.59	239	36.27		2590		824
	-	2.06	1.98	3.08	6.34	237	37.40	2050	2320	665	753
Avr.	-							2050	2455	665	789
	-	2.14	2.10	3.46	7.42	260	35.00	1170	1170	338	338
$A_{87\ 1/2}$	7-12	2.10	2.02	3.21	6.75	240	35.51		1040		324
	-	2.10	2.00	3.14	6.59	237	35.94	1020	1130	325	360
Avr.	-							1095	1113	332	340
	-										No
$A_{93\ 3/4}$	8-7										No
	-										No
Avr.	-										No
	-										No
$A_{96\ 7/8}$	8-8										No
	-										No
Avr.	-										No
	-	2.16	2.05	3.26	7.04	266	37.79		6250		1918
B_{-0}	8-10	2.10	2.05	3.26	6.85	253	37.90	4420	5120	1355	1571
	-	2.15	2.01	3.18	6.84	252	36.85		5340		1678
Avr.	-							4420	5570	1355	1722
	-	2.15	2.00	3.14	6.75	255	37.75		6560		2090
B_{25}	8-10	2.11	2.00	3.14	6.62	252	38.10		6190		1974
	-	2.14	2.00	3.14	6.72	252	37.50		5880		1875
Avr.	-								6210		1980
	-	2.11	2.01	3.18	6.71	250	37.25		3270		1028
B_{50}	8-11	2.13	2.05	3.26	6.94	263	37.92		2930		898
	-	2.18	2.01	3.18	6.93	250	36.05		2830		889
Avr.	-								3010		938
	-	2.14	2.09	3.44	7.35	258	35.10		1070		311
B_{75}	8-14	2.10	2.04	3.27	6.85	256	37.35		1570		486
	-	2.04	2.00	3.14	6.40	240	37.50		1580		503
Avr.	-								1407		431
	-	2.18	2.06	3.33	7.26	256	35.21		1140		342
$B_{87\ 1/2}$	8-15	2.15	2.00	3.14	6.75	244	36.15		975		311
	-	2.15	2.04	3.27	7.04	248	35.26		890		272
Avr.	-								1002		308
	-	2.10	2.03	3.24	6.80	247	36.30	240	320	74	99
$B_{93\ 3/4}$	8-16	2.10	2.03	3.24	6.80	242	35.58		230		71
	-	2.10	2.03	3.24	6.80	243	35.71		190		59
Avr.	-							240	247	74	76
	-	2.00	2.04	3.27	6.54	240	36.70		1040		318
$B_{96\ 7/8}$	8-16	2.15	2.02	3.21	6.90	224	32.45		880		274
	-	2.12	2.01	3.18	6.74	240	31.00		520		164
Avr.	-								813		252

Average of Averages.

A_0 - B_0	1819
A_{25} - B_{25}	1984
A_{50} - B_{50}	1208
A_{75} - B_{75}	610
$A_{87\ 1/2}$ - $B_{87\ 1/2}$	324

Average of Highest Breaks.

A_0 - B_0	2045
A_{25} - B_{25}	2154
A_{50} - B_{50}	1275
A_{75} - B_{75}	663
$A_{87\ 1/2}$ - $B_{87\ 1/2}$	351

†Accidentally broken.

Series II

RESULTS OF COMPRESSION TESTS.

Tested at age of 24 weeks.

(Mortar Specimens)

Serial Number	Date made 1916 Date	Dimensions				Weight		Load		Stress		
		Height	Diam.	Area in Sq. in.	Vol. in Cu. in.	Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.	
	-	2.02	2.02	3.20	6.46	251	38.81	8110	8110	2535	2535	
A_0	6-9	2.03	1.99	3.11	6.32	240	38.00	7770	7770	2500	2500	*
	-	2.03	1.99	3.11	6.32	240	38.00	8720	8720	2810	2810	
Avr.	-							8200	8200	2615	2615	
	-	2.03	2.00	3.14	6.37	251	39.40	9430	9430	3000	3000	
A_{25}	6-9	2.05	1.98	3.08	6.32	245	38.75	8230	8230	2670	2670	*
	-	2.04	1.98	3.08	6.28	242	38.51	7440	7440	2315	2315	
Avr.	-							8366	8366	2661	2661	
	-	2.03	1.99	3.11	6.32	238	37.67	6760	6760	2175	2175	
A_{50}	6-12	2.06	1.98	3.08	6.35	237	37.30	6720	6720	2180	2180	
	-	2.01	1.98	3.08	6.18	237	38.33	6860	6864	2215	2215	
Avr.	-							6780	6781	2190	2190	
	-	2.08	1.99	3.11	6.47	252	38.95	3660	3660	1170	1170	
A_{75}	6-19	2.06	2.03	3.24	6.67	250	37.48	3960	3960	1221	1221	
	-	2.05	1.98	3.08	6.32	248	39.20	3610	3610	1171	1171	
Avr.	-							3743	3743	1187	1187	
	-	2.06	2.02	3.20	6.59	251	38.10	1500	1710	469	534	
$A_{87\ 1/2}$	7-12	2.06	1.97	3.05	6.28	239	38.00	1200	1280	393	420	†
	-	2.05	2.00	3.14	6.44	241	37.45	1850	1850	589	589	§
Avr.	-							1515	1613	1449	514	
	-	2.10	1.93	2.92	6.13	215	39.9	200	255	68.4	68.7	
$A_{93\ 3/4}$	8-7	2.09	1.96	3.01	6.28	245	39.1	100	170	33.3	56.4	
	-	2.06	1.98	3.07	6.32	249	39.4	120	260	39.1	84.6	
Avr.	-							140	228	46.9	69.9	
	-											
$A_{96\ 7/8}$	8-8											
	-											
Avr.	-											
	-	2.10	2.10	3.46	7.26	270	37.2	5000	6600	1445	1910	
B_0	8-10	2.10	2.10	3.46	7.26	268	36.9	7060	7060	2020	2020	
	-	2.10	2.10	3.46	7.26	271	37.3	8800	8800	2542	2542	
Avr.	-							6953	7487	2010	2160	
	-	2.09	2.04	3.26	6.81	267	39.3	6700	6700	2050	2050	
B_{25}	8-10	2.07	2.05	3.30	6.83	260	38.1	5000	6680	1530	2020	
	-	2.05	2.04	3.26	6.68	259	38.8	7450	7450	2285	2285	
Avr.	-							6383	6910	1960	2115	
	-	2.08	2.00	3.14	6.53	267	40.8	2820	2820	897	897	
B_{50}	8-11	2.08	2.00	3.14	6.53	263	40.3	3000	3000	955	955	
	-	2.11	2.04	3.27	6.90	274	39.7	3750	5560	1147	1700	
Avr.	-							3190	3793	1005	1195	
	-	2.08	1.97	3.05	6.34	239	37.7	1000	1020	328	335	
B_{75}	8-14	2.02	2.00	3.14	6.35	238	37.5	1510	1510	480	480	
	-	2.12	2.01	3.17	6.71	260	38.7	1490	1490	470	470	
Avr.	-							1333	1340	428	431	
	-	2.10	2.00	3.14	6.60	245	37.2	1200	1200	382	382	
$B_{87\ 1/2}$	8-15	2.10	2.01	3.17	6.66	257	38.6	1165	1165	368	368	
	-	2.15	1.99	3.11	6.68	236	35.4	960	960	308	308	
Avr.	-							1142	745	353	353	
	-	2.15	2.00	3.14	6.75	237	35.1	770	770	245	245	
$B_{93\ 3/4}$	8-16	2.10	2.00	3.14	6.60	240	36.4	610	610	194	194	
	-	2.05	2.01	3.17	6.50	259	39.8	510	510	161	161	
Avr.	-							630	630	202	202	
	-											
$B_{96\ 7/8}$	8-16											
	-											
	-											
Avr.	-											
		Average of Averages.										
		A_0 - B_0								2312	2387	
		A_{25} - B_{25}								2310	2388	
		A_{50} - B_{50}								1597	1692	
		A_{75} - B_{75}								807	809	
		$A_{87\ 1/2}$ - $B_{87\ 1/2}$								901	434	
		$A_{93\ 3/4}$ - $B_{93\ 3/4}$								124	136	
		Average of Highest Breaks.										
		A_0 - B_0								2676	2676	
		A_{25} - B_{25}								2642	2642	
		A_{50} - B_{50}								1681	1957	
		A_{75} - B_{75}								850	850	
		$A_{87\ 1/2}$ - $B_{87\ 1/2}$								485	485	
		$A_{93\ 3/4}$ - $B_{93\ 3/4}$								157	165	

*Five days late. †Defective. §Two days late.

Series II

RESULTS OF COMPRESSION TESTS.

Tested at age of 52 weeks.

(Mortar Specimens)

Serial Number	Spec's made 1916 Date	Dimensions				Weight		Load		Stress	
		Height inches	Diam. inches	Area in Sq. in.	Vol. in Cu. in.	Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.00	2.00	3.14	6.28	251	39.97	6000	8000	1911	2548
A-0	6-9	2.00	2.00	3.14	6.28	251	39.97	6500	6500	2070	2070
	-	2.00	2.00	3.14	6.28	251	39.97	7500	7500	2385	2385
Avr.	-							6667	7333	2122	2334
	-	2.00	2.00	3.14	6.28	232	36.94	6420	6420	2045	2045
A-25	6-9	2.00	2.00	3.14	6.28	241	38.41	7750	7750	2468	2468
	-	2.00	2.00	3.14	6.28	245	39.01	8280	8280	2618	2618
Avr.	-							7483	7483	2377	2377
	-	2.00	2.02	3.20	6.40	252	39.38	8000	8000	2500	2500
A-50	6-12	2.01	2.04	3.29	6.61	249	37.67	5860	5860	1781	1781
	-	2.02	2.00	3.14	6.34	256	40.37	5200	6690	1656	2131
Avr.	-							6353	6850	1979	2137
	-	2.00	2.00	3.14	6.28	249	37.67	3030	3030	965	965
A-75	6-19	2.16	2.00	3.14	6.28	254	40.44	3380	3380	1076	1076
	-	2.00	2.00	3.14	6.28	240	38.25	2420	2420	771	771
Avr.	-							2943	2943	937	937
	-	2.05	2.00	3.14	6.28	245	39.01	1110	1110	354	354
A-87 1/2	7-12	2.05	2.00	3.14	6.28	244	38.82	1800	1800	573	573
	-	2.00	2.00	3.14	6.28	259	41.40	2000	2000	637	637
Avr.	-							1637	1637	521	521
	-										No
A-93 3/4	8-7										No
	-										No
Avr.	-										No
	-										No
A-96 7/8	8-8										No
	-										No
Avr.	-										No
	-	2.00	2.00	3.14	6.28	247	39.33	10000	10280	3185	3274
B-0	8-10	2.00	2.00	3.14	6.28	255	40.76	12150	12150	3869	3869
	-	2.00	2.00	3.14	6.28	245	39.01	11960	12450	3809	3965
Avr.	-							11370	11627	3621	3703
	-	2.05	2.08	3.39	6.95	272	39.14	5830	5830	1720	1720
B-25	8-10	2.07	2.05	3.30	6.83	270	39.53	7490	7490	2270	2270
	-	2.02	2.05	3.30	6.67	255	38.25	8080	8080	2448	2448
Avr.	-							7133	7133	2146	2146
	-	2.00	2.05	3.30	6.60	251	38.03	960	2410	291	730
B-50	8-11	2.02	2.05	3.30	6.67	257	38.53	3800	3800	1152	1152
	-	2.05	2.06	3.33	6.83	262	38.36	2000	2000	601	601
Avr.	-							2253	2737	681	828
	-	2.04	2.00	3.14	6.21	240	38.65	2000	2000	637	637
B-75	8-14	2.03	2.00	3.14	6.28	239	38.06	2150	2150	685	685
	-	2.05	2.00	3.14	6.28	241	38.38	1580	1580	503	503
Avr.	-							1910	1910	608	608
	-	2.08	2.05	3.30	6.86	255	37.17	4420	4420	1340	1340
B-87 1/2	8-15	2.07	2.03	3.23	6.69	247	36.92	2520	3000	780	929
	-	2.05	2.07	3.36	6.89	267	38.75	3480	3480	1036	1036
Avr.	-							3473	3633	1052	1102
	-	2.05	2.00	3.14	6.28	242	38.54	500	500	159	159
B-93 3/4	8-16	2.04	2.00	3.14	6.28	240	38.22	480	480	153	153
	-	2.05	2.00	3.14	6.28	245	39.01	790	790	252	252
Avr.	-							590	590	188	188
	-	2.06	2.01	3.17	6.53	250	38.28	900	900	284	284
B-96 7/8	8-16										
	-										
Avr.	-							900	900	284	284
	-										

Average of Averages.

A-0 - B-0	3018
A-25 - B-25	2262
A-50 - B50	1482
A-75 - B-75	772
A-87 1/2 - B-87 1/2	812
A-93 3/4 - B-93 3/4	
A-96 7/8 - B-96 7/8	

Series II

RESULTS OF COMPRESSION TESTS.

Tested at age of 104 weeks.

(Mortar Specimens)

Serial Number	Spec's made 1916 Date	Dimensions		Area in Sq. in.	Vol. in Cu. in.	Weight		Load		Stress	
		Height inches	Diam. inches			Total Grams	Unit Grams	1st Cr. Pounds	Ult. Pounds	1st Cr. lb./sq. in.	Ult. lb./sq. in.
	-	2.07	2.10	3 44	7.12	247	34.70	6510	7210	1895	2095
A_{-0}	6-9	2.00	1.98	3.08	6.16	244	39.60	5050	6960	1640	2255
	-	2.04	2.05	3.31	6.75	253	37.45	4440	6930	1340	2095
Avr.	-									1625	2148
	-	2.07	2.01	3.17	6.55	245	37.40	8870	9200	2790	2900
A_{-25}	6-9	2.02	1.98	3.08	6.23	237	38.05	3000	5200	975	1685
	-										
Avr.	-									1883	2293
	-	2.05	2.03	3.20	6.57	251	38.20	4700	6080	1465	1895
A_{-50}	6-12	2.04	2.03	3.20	6.54	244	37 30		2610		815
	-										
Avr.	-										1355
	-	2.10	2.03	3.20	6.72	254	37.75		3000		938
A_{-75}	6-19	2.08	2.00	3.14	6.54	239	36.55		2420		768
	-	2.07	2.01	3.17	6.56	243	37.00		3200		1010
Avr.	-										905
	-										
$A_{-87\ 1/2}$	7-12										
	-										
Avr.	-										
	-	2.14	2.01	3.17	6.78	252	37.15				No
$A_{-93\ 3/4}$	8-7	2.15	1.99	3.11	6.69	242	36.15				No
	-	2.16	1.98	3.08	6.67	242	36.25				No
Avr.	-										No
	-										
$A_{-96\ 7/8}$	8-8										
	-										
Avr.	-										
	-	2.20	2.04	3.27	7.20	260	36.10	9650	9650	2950	2950
B_{-0}	8-10	2.20	2.00	3.14	6.92	242	34.95	2580	5470	820	1735
	-										
Avr.	-									1885	2343
	-	2.16	2.06	3.33	7.19	240	33.40	3530	7150	1059	2148
B_{-25}	8-10	2.20	2.06	3.33	7.33	252	34.38	4150	4380	1248	1318
	-										
B_{-0}	8-10	2.20	2.00	3.14	6.92	242	34.95	2580	5470	820	1735
	-										
B_{-50}	8-11										
	-										
Avr.	-										
	-	2.14	2.08	3.41	7.30	270	36.95	1190	1730	350	508
B_{75}	8-14	2.22	2.06	3.34	7.43	272	36.60	1220	1690	365	507
	-	2.24	2.04	3.27	7.33	275	37.50	1560	2280	478	698
Avr.	-									398	571
	-	2.16	2.08	3.41	7.36	255	34.60	1760	1760	518	518
$B_{-87\ 1/2}$	8-15	2.14	2.00	3.14	6.72	257	38.25	1790	1790	570	570
	-	2.22	2.06	3.34	7.42	265	35.70	1110	1110	332	332
Avr.	-									473	473
	-	2.22	2.00	3.14	6.98	260	37.20	360	610	114	194
$B_{-93\ 3/4}$	8-16	2.20	2.05	3.31	7.28	257	35.30	810	1430	245	433
	-										
Avr.	-									190	314
	-										
$B_{-96\ 7/8}$	8-16										
	-										
Avr.	-										
	-										

Average of Averages.

A_0 - B_0	2245
A_{25} - B_{25}	3882
A_{50} - B_{50}	
A_{75} - B_{75}	738
$A_{87\ 1/2}$ - $B_{87\ 1/2}$	
$A_{93\ 3/4}$ - $B_{93\ 3/4}$	
$A_{96\ 7/8}$ - $B_{96\ 7/8}$	

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Vol. 5, No. 2, March, 1913. 42nd Annual Catalogue, 1912-1913.

Vol. 5, No. 3, Never Published.

Vol. 5, No. 4, Never Published.

Vol. 6, No. 1, Never Published.

Vol. 6, No. 2, March, 1914. 43rd Annual Catalogue, 1913-14.

Vol. 6, No. 3, Never Published.

Vol. 6, No. 4, Never Published.

Vol. 7, No. 1, Never Published.

Vol. 7, No. 2, March, 1915. 44th Annual Catalogue, 1914-1915.

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Vol. 7, No. 4, September, 1915. Register of graduates, 1874-1915.

Vol. 8, No. 1, Jan., 1916. Bibliography on concentrating ores by flotation. Jesse Cunningham.

Vol. 8, No. 2, March, 1916. 45th Annual Catalogue, 1915-1916.

Vol. 8, No. 3, June, 1916. The Business of mining. W. R. Ingalls. (Commencement address, May 26, 1916.)

Vol. 8, No. 4, October, 1916. Register of graduates, 1874-1916. (Out of print.)

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Vol. 10, No. 1, Never published.

Vol. 10, No 2, March, 1918. 47th Annual Catalogue 1917-18.

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